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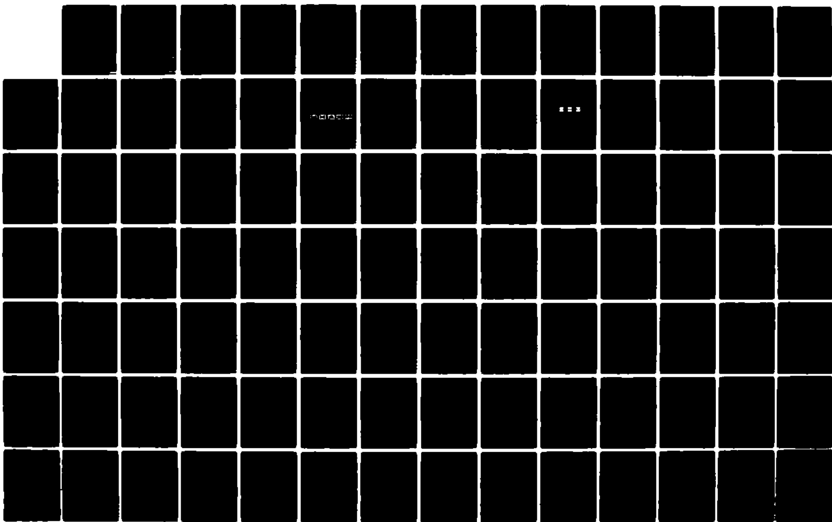

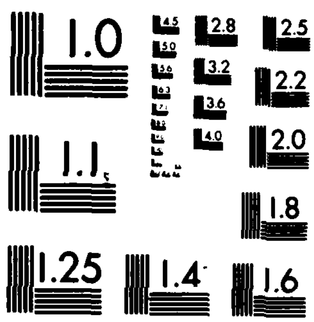

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GPS RANGE APPLICATIONS STUDY
FINAL REPORT

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31 DECEMBER 1982

FINAL REPORT

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Prepared for

WESTERN SPACE AND MISSILE CENTER
Vandenberg Air Force Base, California 93437

This final report was submitted by The Analytic Sciences Corporation, One Jacob Way, Reading, MA 01867, under Contract F04703-82-C-0220 with the Western Space and Missile Center, Vandenberg Air Force Base, CA 93437. Operations Research Analyst, Mr. J. McConnell, WSMC/XRQA, was the Division Project Engineer-in-Charge. This technical report has been reviewed and is approved for publication.

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The GPS Range Applications Study assessed the potential cost benefits of GPS for test and evaluation applications. Generalized GPS-based and non-GPS-based test support equipment configurations for eight generically-derived DoD test ranges were defined, and a comparative evaluation of performance capabilities (against requirements) and of 20 year life cycle costs were performed. Based on these analyses, a prioritized ranking of recommended GPS test support applications was generated. A preliminary description of desirable characterist

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20. ABSTRACT (continued)

of a family of GPS Instrumentation Equipment (IE) was developed, and a series of technical issues requiring resolution through field test was identified.

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1. EXECUTIVE SUMMARY

This study was performed in support of the Tri-Service ad hoc steering group to evaluate the potential applicability of the Global Positioning System (GPS) as a source of Time Space Position Information (TSPI) for test and training range activities. In order to provide broad applicability to DoD test and evaluation activities, the study focused on eight generic test and training ranges patterned after 20 major DoD ranges. Possible cost benefits for these generic ranges were evaluated through a comparative analysis of GPS- and non-GPS-based TSPI alternatives, considering both near-term (1985-1987) and far-term (1988+) transitions to GPS. Although some functional differences necessarily arose, every effort was made to compare alternative system concepts with comparable capabilities. To this end, each system option considered was required to support the basic TSPI, down-link, and command and control requirements for the specified test arena and time frame. Near-term requirements were relatively consistent with existing national range capabilities; however, the far-term requirements were allowed to grow to encompass service-derived requirements for the 1988+ time frame. Frequently, this groundrule dictated significant far-term improvements in such system parameters as accuracy, coverage volume, data rate, or number of players.

An overview of the study methodology is provided in Section 1.1. Section 1.2 summarizes the principal study results, and Section 1.3 provides specific recommendations for GPS equipment development. An overview of the entire report is presented in Section 1.4.

1.1 METHODOLOGY OVERVIEW

The study was performed by TASC, with subcontractor support from the BDM Corporation, utilizing a requirements and capabilities data base generated by the Tri-Service GPS Steering Committee. The types of information provided in this data base and its relationship to the principal study tasks is indicated in Fig. 1.1-1. The methodology employed in completing these tasks is summarized below.

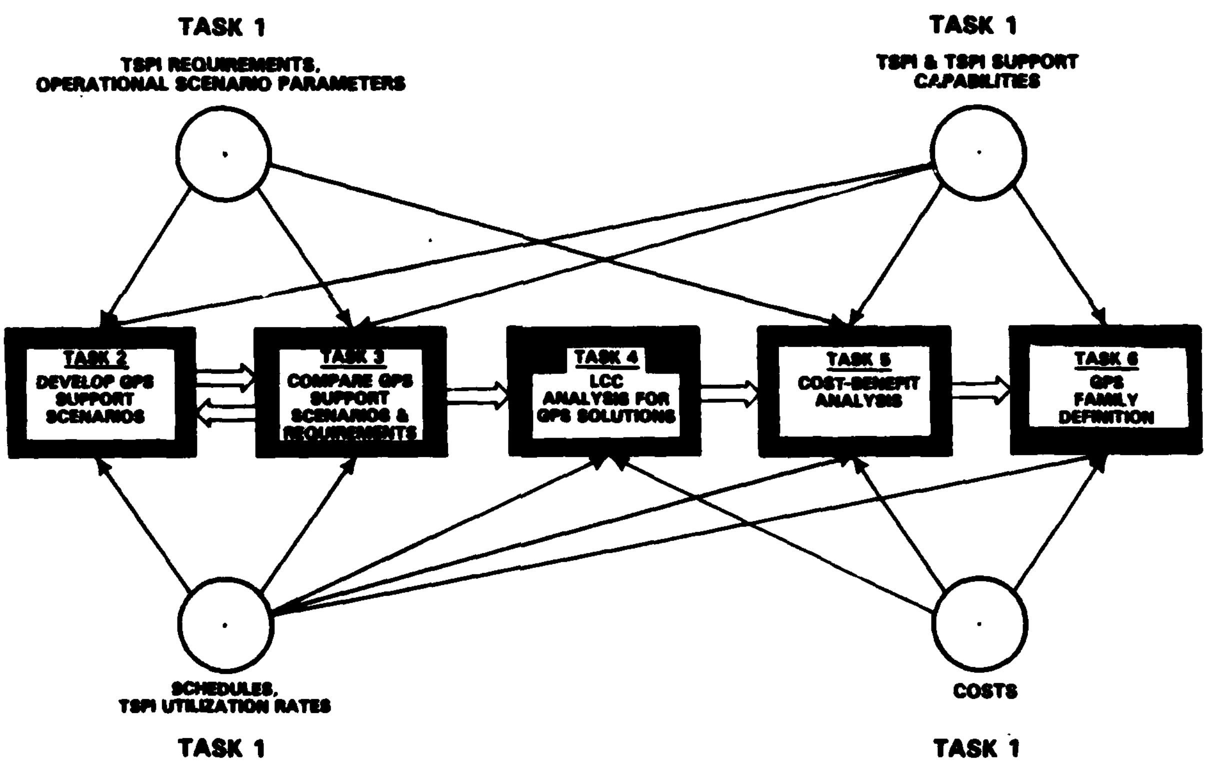

Figure 1.1-1 Task Relationships and Data Flow

<u>GPS Support Scenario Development</u> - Using an expanded version of the Tri-Service Steering Committee data base, GPS support scenarios were developed for each generic range in terms of test categories supported, range topography, and performance requirements. Both near-term and far-term non-GPS

instrumentation configurations were defined, with the near-term equipment conforming to representative existing equipment. Complements of near-term and far-term GPS-based equipments were then specified for each generic range. Top-level block diagrams of system configurations incorporating both ground-based and on-board GPS instrumentations were generated to serve as a basis for concept evaluation. These configurations included the appropriate down-link and command and control interfaces.

GPS Support Scenarios and Requirements Comparison - The second step was to assess expected GPS and non-GPS capabilities in such performance-related areas as real-time and post-mission accuracy, available data rate and time after turn-on for first fix. For the case of GPS, these performance parameters were derived as a function of equipment configuration parameters such as GPS code and frequencies utilized, number of receiver channels implemented, and autonomous vs differential operation (the removal of bias-like errors with a surveyed receiver). With potential GPS capability established, GPS configurations were compared to requirements in an iterative fashion until the best match or matches was made. To complete this portion of the analysis, performance and implementation issues were identified for each candidate configuration along with the associated risks.

Life-Cycle Cost Analysis for GPS Solutions - The Life-Cycle Cost (LCC) analysis was developed from differential (rather than total) costs to implement and support three options for each generic range: 1) all GPS, 2) all non-GPS, and 3) near-term non-GPS transitioning to far-term GPS. The cost comparison encompassed the basic TSPI, down-link, and command and control functions, although the differential approach eliminated the need to estimate costs for many command and control system elements common to both GPS and non-GPS configurations. Because

of the nature of the study, Rough-Order-of-Magnitude (ROM) Development, Acquisition, and Operation and Maintenance (O&M) costs were utilized for generic instrumentation representative of existing or planned equipments. Costs associated with specific GPS user equipment were estimated based on discussions with the GPS Joint Program Office (JPO) and prospective GPS equipment vendors. Specific non-GPS TSPI equipment costs were extracted from TASC and BDM corporate data bases and government-approved study documentation.

Cost-Benefit Analysis - The evaluation of GPS effectiveness as a TSPI source was predicated upon its performance and operational features relative to non-GPS alternatives in each scenario as gauged against a set of Measures-of-Merit (MOM). These criteria were separated into quantitative requirement "Drivers" and non-quantitative "Considerations". The former included such factors as real-time and post-test accuracy, coverage area, and minimum coverage altitude; the latter encompassed many of the "ilities". After rating each near- and far-term test application on a generic range, a rating was developed for the range as a whole. These ratings were then combined with the LCC analysis results to rank the overall cost-effectiveness of each range, resulting in a prioritized list of applications.

GPS Family Definition - The characteristics of a family of GPS instrumentation which could satisfy all or most of the requirements of each GPS application were defined in terms of key design parameters and operating capabilities. Modularity was stressed so that a minimum number of subsystems would have to be developed. A matrix of potential applications for each member of the family was then generated which, along with the list of prioritized applications, will serve as a basis for planning instrumentation development.

1.2 RESULTS AND CONCLUSIONS

A summary of the composite differential LCC estimates for seven of the eight generic ranges over a 20 year period (1985-2004) is shown in Fig. 1.2-1*. The composite figure indicates that GPS-based TSPI offers, in general, lower total costs, primarily due to higher O&M costs associated with non-GPS equipments, such as radars and support aircraft. However, it should be noted that on two of the seven generic ranges, the all-non-GPS options were more economical and on 3 other ranges, the lowest cost solution was the near-term non-GPS/far-term GPS option. Although projections from eight generic ranges to the 20+ major DOD test and evaluation ranges is problematical, the LCC results suggest that 20 year LCC savings of as much as \$1.1-1.5B could be realized if GPS were efficiently integrated into range operations.

Conclusions concerning possible LCC savings were drawn after examining both baseline cost estimates as well as scenario and cost excursions from nominal values. The parameters that were varied differed from range-to-range, depending upon which costs were drivers. For example, in some non-GPS options, phased array and dish radar O&M costs were perturbed up and down by 25 percent, or support aircraft requirements were varied from 3 to 5 hours per mission. For the GPS options, the number and cost of translators and receivers were typically varied to reflect uncertainties in those numbers. The net effect of performing these cost excursions was to ensure that meaningful conclusions were obtained from the ROM cost estimates.

*A cost analysis for the eighth generic range, Sea-Based (Moving), was deleted because of the lack of basic cost data; however, GPS would represent an additional cost for this range.

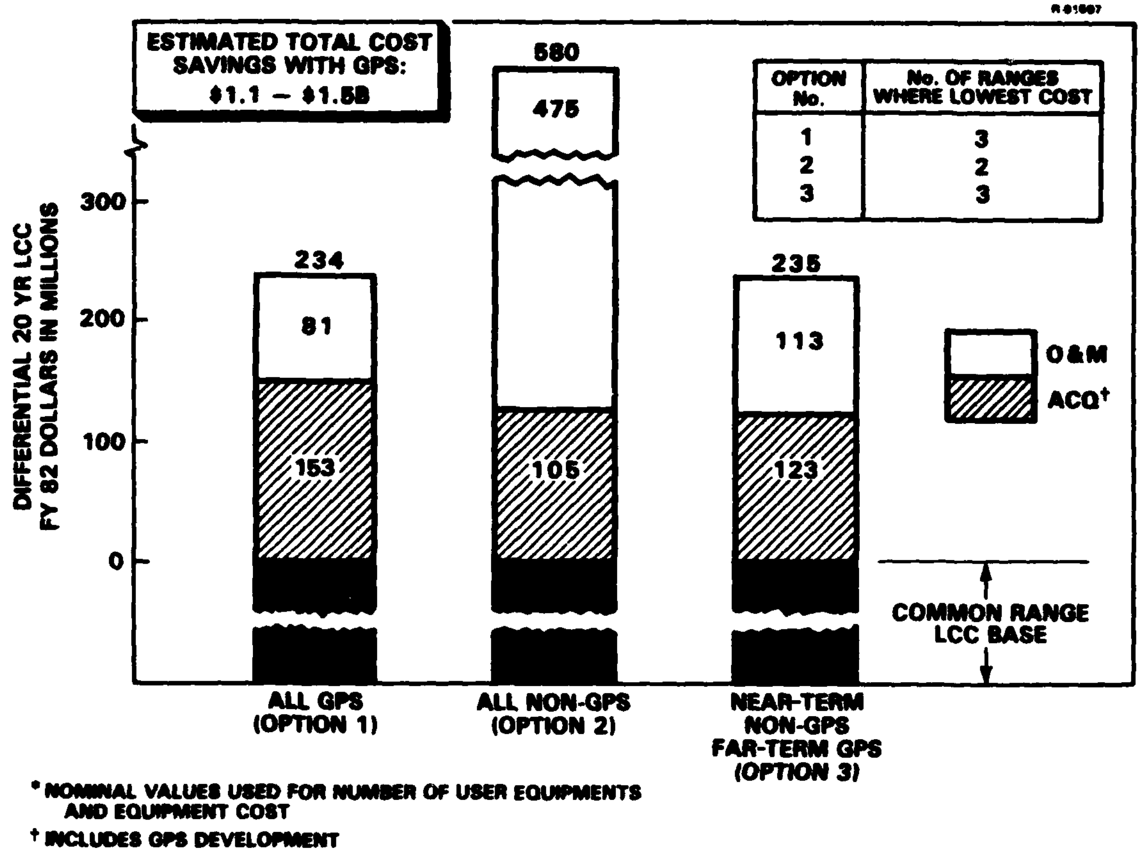

Figure 1.2-1 Differential LCC Summary (Seven Range Composite)

Potential applications for GPS were evaluated through a screening process in which generic range cost and effectiveness played a major role. First, the results of the differential LCC and composite effectiveness analysis were checked for consistency; i.e., which option offered the lowest cost and high relative effectiveness in the time frame considered. In most cases, the preferred implementation (GPS or non-GPS) in a particular time frame was apparent. For two of the ranges, however, GPS appears to offer accuracy and operational advantages which may outweigh cost considerations. The results of this comparison are presented in Table 1.2-1.

TABLE 1.2-1
COST EFFECTIVENESS (NEAR/FAR TERM)

GENERIC RANGE	LOWEST COST	GPS RELATIVE EFFECTIVENESS	PREFERRED IMPLEMENTATION
Long-Range	GPS/GPS	High/High	GPS/GPS
Extended-Range	GPS/GPS	Low/High	GPS/GPS
Short-Range (Land)	Non-GPS/GPS	High/High	Non-GPS/GPS
Short-Range (Water)	Non-GPS/GPS*	Moderate/High	Non-GPS/GPS
Airborne	GPS/GPS	High/High	GPS/GPS
Land-Based	Non-GPS/Non-GPS*	High/High	Non-GPS/GPS
Sea-Based (Fixed) Over-Land At-Sea	Non-GPS/GPS	Low/Moderate -/High	Non-GPS/GPS
Sea-Based (Moving) OT&E Training	-/Non-GPS	-/High -/Moderate	-/GPS†

*Not clear cut winner.

-Near term capability does not exist.

†Augmentation of basic system to exploit GPS.

The high relative effectiveness attributed to GPS in many of the generic ranges was due in most instances to a combination of a moderate improvement in accuracy (particularly in velocity measurement), and a significant improvement in coverage area and minimum altitude coverage. The relative insensitivity of GPS to measurement geometry variations (GDOP) was judged to be a major asset in improving coverage. On the negative side, there are unresolved questions coverning the extent to which antenna masking would make pod-mounted GPS receivers a viable option, and whether or not GPS equipment

can be made compact and inexpensive enough to meet the TSPI requirements for small, expendable test articles.

1.3 RECOMMENDATIONS

<u>GPS Family</u> - The recommended family of GPS instrumentation equipments for test and training range applications is shown in Table 1.3-1. The issues to be addressed in specifying a GPS family of instrumentation equipment include performance (accuracy, data rate, dynamics tolerance), output data format, external equipment interfaces, size, and cost. To a significant extent, performance can be traded off against other design parameters. These tradeoffs led to a recommendation of two receiver types for the GPS instrumentation family: a full capability design emphasizing performance; and a basic capability design emphasizing minimum cost and size. Even the basic capability receiver may not be able to meet the size and cost constraints of some expendable test articles, however, necessitating the development of two classes of GPS translators. The Geoceiver and Timing Receiver equipments are off-the-shelf designs which will be used to support overall range operations. A matrix showing potential applications for each component of the family is given in Table 1.3-2.)

The two recommended classes of receivers should be modular in nature and contain features to ensure flexibility in the range environment. To enhance commonality between the Full and Basic Capability sets, they should utilize, at a minimum, interchangeable L_1 frequency RF front-end, oscillator, data processor, data reader and telemetry interface modules. To exploit the planned modularity, the translator signal receiver used in conjunction with translators could be synthesized from the Full Capability set components, except for a

TABLE 1.3-1
PRELIMINARY GPS INSTRUMENTATION FAMILY*

PARAMETERS	RECEIVERS		TRANSLATORS		GEOCEIVER	TIMING RECEIVER
	FULL** CAPABILITY	BASIC CAPABILITY	LOW POWER	HIGH POWER		
Channels	5	2§	-	-	1	1
Codes	P, C/A	P, C/A	C/A	C/A	P, C/A	C/A
Frequency	L_1†, L_2	L_1	L_1	L_1	L_1, L_2	L_1
Size (in^3)	<600††	<450††	<30	<140	<3500	2000
Weight (lb)	<40	<25	<3	<10	<50	35
Power (W)	<140	<100	<45	<100	<100	300

*1985 Projections.

**Two packaging options: rack-compatible and pod-mounted.

†Translator signal receiver will have common components except for an RF down link front-end module.

††Includes removable data processor module.

§Single channel appropriate if certain performance limitations are satisfactory.

different RF front-end and modified data processing software. Existing or planned GPS Joint Program Office (JPO) antennas should be utilized in applications not requiring pod or missile-borne antennas to take advantage of programmed commonality. Some of the shared features of both test article receivers are, in addition to modular design, the capability to acquire, track and navigate with C/A or P code; output either ρ, $\dot{\rho}$ (pseudo-range, delta range) or x, y, z, t; accommodate auxiliary inputs; and receive transmissions from ground pseudolites. In addition to the aforementioned features, the Full Capability receiver should also be able to accept inertial aiding, track L_2 code signals, accept ρ, $\dot{\rho}$ corrections and satellite designations, and output data at a higher rate (20 Hz vs 1 Hz).

TABLE 1.3-2
POTENTIAL APPLICATIONS FOR
GPS RECEIVERS AND TRANSLATORS

APPLICATIONS	TEST ARTICLE RECEIVERS		TRANSLATORS		GEOCEIVER	TIMING RECEIVER
	FULL CAPABILITY	BASIC CAPABILITY	LOW POWER	HIGH POWER		
Test Articles						
• Aircraft	X*	X	X*			
• Drones	X*	X	X			
• Large Short Range Missiles	X*		X*			
• Small Short Range Missiles			X*			
• Land Vehicle		X				
• Ships		X				
• Strategic Missile				X		
• Anti-Ballistic Missile	X*++		X*++	X		
• Anti-Satellite Missile				X*		
• Cruise Missile	X		X*			
Baseline Range Equipment:						
• Differential GPS Reference		X				
• Translator Receiver	X†					
• Rawinsonde Tracker			X			
• Survey			X**		X	
• Time Reference						X

*IMU Aiding Desirable
†Translator Signal Receiver With S-Band Front End Module
**SMILS Positioning
++High "g" Endo-Atmospheric Interceptor May be Poor GPS Application

Translators should be designed to receive only C/A-code signals broadcast on the L_1 frequency. Features should include selectable output power and output center frequency, a capability to accept and output a pilot tone and the capability to interface with transdigitizer and encoding or encryption devices. An option to accept external power should also be provided. These features plus common antennas (where missile diameters permit) will serve to enhance flexibility in a multiple test article environment.

Implementation Priority - Table 1.3-3 lists, by generic range and time frame, the recommended implementation priority for GPS based upon the cost-effectiveness ratings shown in Table 1.2-1. Included in the table is a list of test articles for which GPS received high ratings in time frames corresponding to those in the table. It should be noted that GPS is the preferred near-term option for only three of the ranges but that GPS offers significant performance advantages for all ranges in the far-term.

TABLE 1.3-3
PRIORITIZED APPLICATIONS

GENERIC RANGE (BY PRIORITY)		RANGE CATEGORY	TEST ARTICLE	TIME FRAME	
				NEAR-TERM	FAR-TERM
1	Airborne	OT&E, Training	Aircraft, Drones, Cruise Missile	GPS	GPS
	Long-Range	DT&E, OT&E	Ballistic Missiles, ABM, SMILS	GPS	GPS
	Extended-Range	DT&E, OT&E	Cruise Missile, Bomber	GPS	GPS
2	Sea-Based (Fixed)	OT&E, Training	Aircraft, Missile, Ship		GPS
	Short-Range (Land)	DT&E, OT&E	Aircraft, Drones, Missiles		GPS
	Short-Range (Water)	DT&E, OT&E	Aircraft, Drones, Missiles		GPS
3	Land-Based	OT&E, Training	Aircraft, Drones, Land Vehicles, Troops		GPS
	Sea-Based (Moving)	OT&E, Training	Ships, Aircraft		GPS

1.4 OVERVIEW OF REPORT

Chapter 2 provides an overview of the Global Positioning System. Performance and design related issues associated with both the overall system and particular receiver designs are analyzed in Chapter 3. Chapter 4 presents the study methodology, followed in Chapters 5 through 12 by the study results for each of the eight generic ranges. Recommendations for GPS equipment development are presented in Chapter 13.

2. GPS OVERVIEW

This chapter provides a short, general introduction to the Global Positioning System (GPS) and to GPS-based Time Space Position Information (TSPI) equipment concepts. Section 2.1 covers system operation, including the GPS satellites, system ground control equipment, and the transmitted signals. Section 2.2 focuses more specifically on conceptual user equipments suitable for various range instrumentation applications. More detailed discussions of design tradeoffs, performance, cost, and effectiveness are presented in subsequent chapters.

2.1 SYSTEM OPERATION

The NAVSTAR Global Positioning System (GPS) is a space-based radio navigation system designed to provide users with worldwide, three-dimensional position and velocity information along with coordinated universal time (UTC) (Refs. 6 and 9). GPS consists of three primary segments: (1) a space segment -- satellites that transmit radio signals, (2) a control segment -- ground-based equipment to monitor the satellites and update the data content of their signals, and (3) a user equipment segment--devices that passively receive and process satellite signals into user information. In addition, the system can admit pseudolites--ground-based GPS signal generators producing satellite-like signals for range instrumentation applications.

Satellites - The space segment will ultimately consist of a constellation of 18 GPS satellites in circular orbits with 12 hour periods (at 10,900 nm altitude). The common period was

was chosen so that the satellite ground tracks repeat every (sidereal) day. Each satellite has an onboard propulsion system to maintain its orbital position and is equipped with extremely accurate atomic clocks, radio transmitters and receivers. These are powered by solar panels and by back-up batteries for eclipse periods.

The baseline operational constellation (Phase III) has the 18 satellites in six orbital planes, each with an orbital inclination of 55 deg and separated by 60 degrees in right ascension (Fig. 2.1-1, Ref. 7 or 8). The three satellites within a plane are evenly spread 120 deg apart in true anomaly. Other constellation alternatives exist, including a three plane version and the possibility of eventually increasing the constellation to 24 satellites.

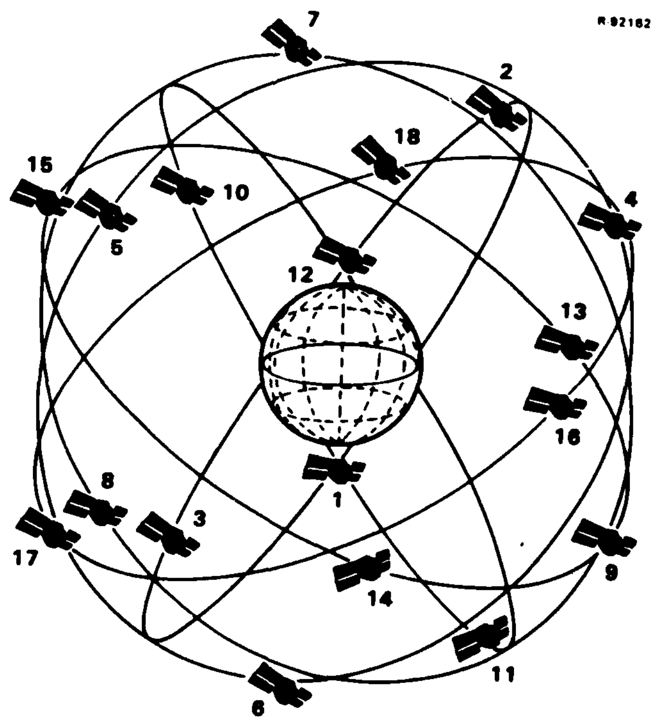

Figure 2.1-1 The GPS 6-Plane, 18-Satellite Constellation (Ref. 7)

The current test constellation (Phase II) consists of four full capability satellites, one with degraded navigation capabilities, and one with no navigation capability. These satellites are not evenly spread in orbit, but are "bunched" so that four or more are visible for several hours a day at most locations. The launch of the next satellite is scheduled for May 1983, and three additional satellites are in various states of final test or in storage (Ref. 6). Figure 2.1-2 shows the GPS Program Schedule.

GPS Signals - All of the GPS satellites continuously broadcast on the same two L-band radio frequencies, denoted as L_1 (1575.42 MHz = 154 × 10.23 MHz) and L_2 (1227.6 MHz = 120 × 10.23 MHz). Superimposed on these carriers are two coded signals unique to each satellite: a precise or P-code pseudo-random noise (PN) signal with a 10.23 MHz bit rate (see Fig. 2.1-3) and a coarse/acquisition or C/A-code PN signal with a 1.023 MHz chip rate. The L_1 frequency contains both the P- and C/A-code signals, while the L_2 frequency contains one or the other, not both. Superimposed on the P- and C/A-codes are 50 Hz (20 msec bits) navigation data signals containing the navigation message (Ref. 10) necessary for the user to compute satellite positions and velocities, satellite health and status, and, ultimately, user position, velocity, time, and frequency. The use of both the L_1 and L_2 frequencies allows the user to adjust for signal group delay caused by the ionosphere, which would (at times) otherwise constitute a large source of user positioning error (Ref. 12).

It is the C/A-and P-codes that uniquely identify and allow the user to acquire the signals from a given satellite. While there are plans for 18 satellites (possibly 24), there are 37 different C/A- and P-codes built into the system. This excess allows for spare satellites and also allows for the use

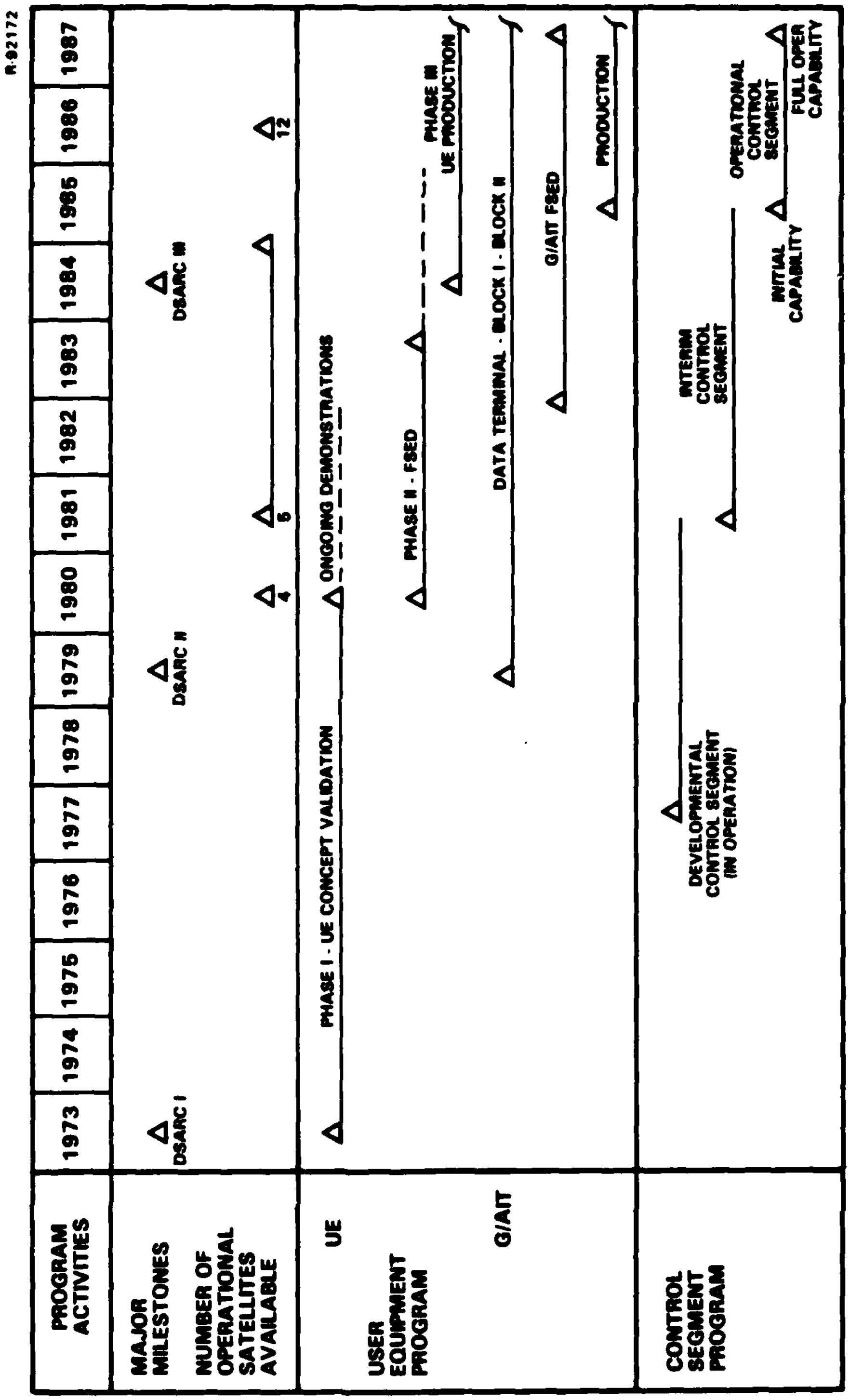

Figure 2.1-2 GPS Program Schedule (Ref. 4)

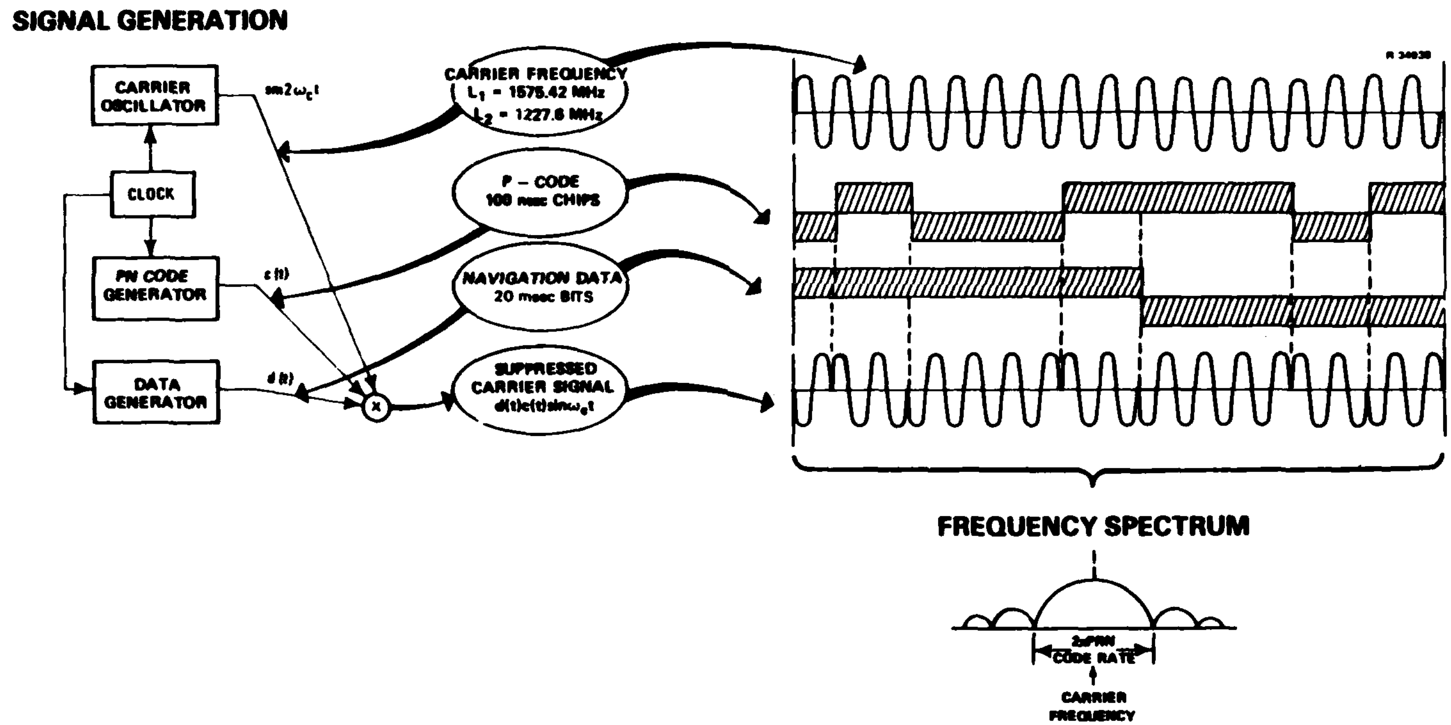

Figure 2.1-3 GPS Signal Structure (P-Code)

of GPS pseudolites (ground transmitters) without any change in user receiver characteristics.*

The C/A-codes all repeat every millisecond. That is, each C/A-code may be thought of as a fixed string of ones and zero's that is 1023 chips long and is constantly repeating. Each chip of the C/A-code lasts just less than one microsecond, which, at the speed of light, is about 1000 ft. The P-code chips are only one tenth as long (100 ft). The P-code transmissions do not repeat in practical terms. In fact, there is only one P-code sequence which is about 37 weeks long -- each satellite uses a one-week-long segment of the P-code that is initialized at the beginning of the week. Because the P-code is so long and does not repeat, it is impractical to acquire it in a random search. The short C/A-code, however, is easily acquired, in a few seconds in many situations, which is why it is designated as the clear/acquisition code.

Once the C/A-code is acquired, the navigation message may be interpreted. This 50 Hz data stream comes in "frames" that are 1500 bits long (lasting 30 sec) and are divided into five subframes of 6 sec duration (Fig. 2.1-4). Each subframe contains a "handover word" (HOW) that essentially tells the user the time when the subframe was transmitted, allowing a user with knowledge of the P-code initializations to acquire the P-code for the particular satellite in question. The rest of the navigation message contains precise information about the location and clock synchronization of the satellite sending the message (the precision emphemeris) and less precise but similar information about all the other satellites (the almanac). The precise information is repeated every frame (although it

*Some change in user navigation processing is necessary for pseudolite data, as ground transmitters obviously are not described by satellite orbits. Modifications to increase the number of codes beyond 37 are also possible.

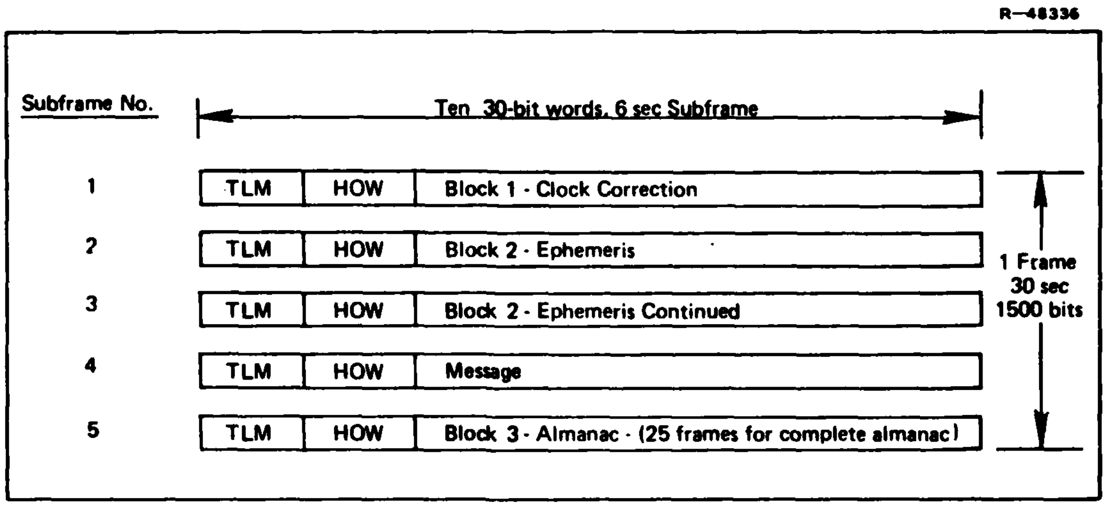

Figure 2.1-4 GPS Navigation Data Format -- Frame and Subframe Structure

changes only once per hour). The almanac data is transmitted on a one-satellite-per-frame basis, so several frames must be interpreted to acquire all of it.

Control Segment - The operational control segment consists of five monitor stations, a master control station, and two ground antennas (Ref. 6). Each monitor station consists of a user receiver, a computer, and various test equipments. The monitor stations (whose locations are very precisely known) receive satellite signal data and transmit this information to the master control station where it is processed to determine satellite orbit parameters and signal (clock) accuracy. The master station produces messages to correct for any discrepancies and relays them to the uplink transmitter for transmission to the satellites. These messages also include the navigation message data transmitted by the satellites and may include instructions for "altering" or encrypting the navigation signals and data. This could be done to deny or degrade the system to

all but specifically authorized users -- generally referred to as "Selective Availability."

2.2 CONCEPTUAL TSPI USER EQUIPMENT DESCRIPTIONS

GPS-based TSPI data may be obtained from either an onboard receiver or translator. The receiver can provide TSPI data in the form of pseudo-range and delta range measurements with a minimum of onboard processing, or position and velocity measurements in cartesian coordinates with a moderate amount of onboard processing. In either case, the measurements can be recorded for post-test processing or telemetered to the ground if real-time processing is required (see Fig. 2.2-1). Translators act as wideband RF relays which frequency shift (typically to S-band) and re-transmit the unprocessed GPS signals to a ground station. The ground station would either wideband record the unprocessed signals for post-mission processing or signal detect and process the signals (using a modified receiver processor) if real-time tracking is required (see Fig. 2.2-2).

Because translators perform a relatively simple function, they tend to be less expensive than a full-up receiver and require less volume. As a consequence, they are well-suited for small, expendable vehicles. However, spectrum allocation requirements tend to limit the number of translators which can broadcast simultaneously.

For non-expendable applications such as aircraft, receivers (pod-mounted or operational) become prime TSPI candidates, although translators may be a viable option in scenarios where translator-based missile tracking is not done simultaneously. For missiles and drones (which will suffer

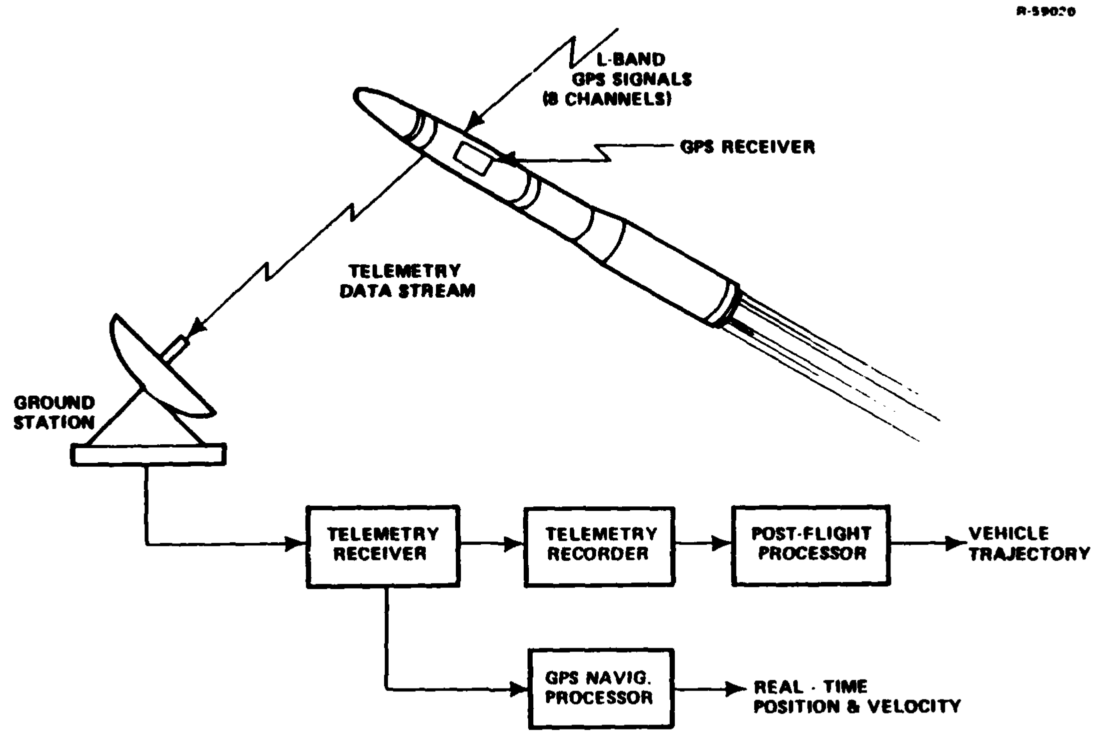

Figure 2.2-1 Example of GPS Receiver Concept -- Tracking Data Telemetered to Ground-Based Navigation Processor

attrition either intentionally or inadvertently) the choice will most likely be driven by a combination of available volume and unit cost. In general, however, the type of onboard TSPI equipment chosen will be dictated by performance requirements, form-fit factors, and cost relative to that of the test article itself.

GPS Receivers - The receiver approach requires from 1 to 4 parallel channels for tracking 4 satellites on the L_1 frequency, plus an additional channel if the L_2 frequency is to be tracked for ionospheric corrections. (The latter may be eliminated if a surveyed reference (ground) receiver is available to remove systematic errors through differential corrections, or used to reduce acquisition times for "new" satellites.)

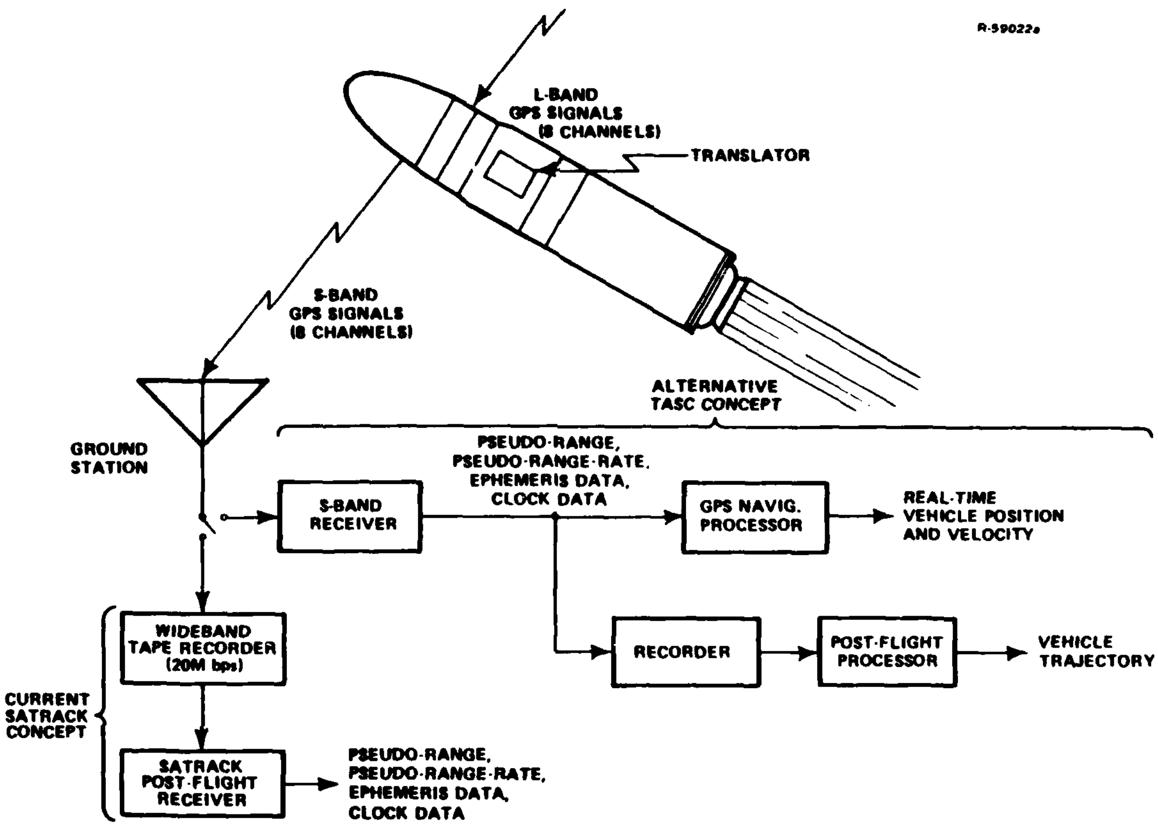

Figure 2.2-2 Example of GPS Translator Concept

The determination of the exact number of channels (1 through 5) depends on the tracking accuracy and data rate required, the vehicle dynamics, and whether or not an inertial system can provide carrier loop aiding.

In general, configurations employing less than 4 parallel channels must <u>sequence</u> through the 4 satellite signals. Hence, for some period of time, a given satellite signal is not being tracked. When the receiver returns to the untracked signal, it must first pull-in the sign ` and then reinitiate tracking. In high dynamic applications, the uncertainty in signal pseudo-range and doppler may have grown to where they

lie outside of the pull-in range of the tracking loop. To eliminate this possibility, an inertial system could aid the receiver to compensate for these dynamics-induced signal uncertainties, or a non-sequential receiver configuration could be used. The decision would be based on the availability of an inertial system, the complexity of integrating it with the sequential GPS set, and the added cost of a non-sequential set over a sequential set.

The receiver would provide either position and velocity fixes or simply measure pseudo-ranges, delta ranges (roughly equivalent to doppler), and time, from which a TSPI solution could be derived. For real-time processing, either form of data would be telemetered to a ground station. The surface support equipment would consist simply of the basic telemetry receiving and recording equipment and simple data processing logic for the case where a TSPI solution is not provided by the onboard GPS set. A unique feature of this approach is that the GPS time data can be used by other onboard instrumentation equipment for time tagging.

<u>GPS Translators</u> - As Fig. 2.2-2 indicates, the translator concept can be implemented with either real-time reception of the translated signal (which may be desirable for range safety and quick-look purposes) or wideband recording of the downconverted S-Band signal (current SATRACK system) for subsequent processing. Both translator concepts could use the same onboard translator design, but the recording (SATRACK) concept introduces considerable additional ground support complexity and cost.

The principal advantage of a recorded translator system is that it guards against unnecessarily long <u>signal dropout</u> due to signal fading, antenna blockage, high jerk or acceleration

levels, etc. For the real-time translator option, significant signal drop-outs could require mode transition from tracking (data collection) to acquisition/reacquisition, which could cause an extended data loss in low signal-to-noise or high dynamic environments.* The latter may be mitigated by telemetering data from an onboard IMU (where available) to provide aiding signals to a remote receiver (if delays due to encoding and decoding the IMU data can be compensated to permit synchronization with the translator signals). With the recorded translator concept, however, the data stream could be reprocessed until the only data loss was the actual duration of the signal drop-out interval.

Both translator approaches consist of a wide band repeater capable of translating the L_1 and L_2 GPS signals up to S-band (2.20-2.29 GHz) or, in certain applications, down to UHF. These signals would be retransmitted for processing by the ground terminal. The real-time translator approach would require a GPS receiver (with a special RF front-end and software) to acquire and simultaneously track the best 4 translated GPS signals for measuring pseudo-range and delta range. The recorded translator approach would simply downconvert the received signal to the GPS code bandwidth (2 MHz for C/A-code; 20 MHz for P-code), then digitize and record the downconverted signal. A specially designed post-flight receiver would then extract and "receive" four (or more) GPS satellite signals from the tape.

Both approaches introduce a common propagation delay from the vehicle to the ground station and a common delta range

*Signal drop-outs would also induce mode transitions for onboard receivers. Onboard IMU data would be helpful in minimizing the length of the reacquisition period following lengthy signal dropouts, however, non-IMU-aided receivers can successfully reacquire following signal recovery.

(doppler shift) to each of the signals. These "bias errors" are removed by a hyperbolic four satellite navigation solution. Both translator approaches could require (in addition to the S-band receiver) a normal L-band GPS receiver at the ground station to assist in ionospheric corrections and in signal acquisition. They will also require carefully designed L and S band antennas on the vehicle to minimize phase error, and will (typically) need a relatively high gain antenna on the surface.

3. GPS DESIGN ANALYSIS

A number of significant design issues must be addressed when specifying GPS-based TSPI configurations. Those specifically related to the test article GPS equipment are evaluated in this chapter. Section 3.1 discusses performance tradeoffs which impact either accuracy or data rate. Section 3.2 summarizes the available outputs and the limitations on obtaining data from existing GPS receivers. GPS equipment size, weight, and power projections are presented in Section 3.3, followed by recommended GPS instrumentation configurations in Section 3.4.

3.1 PERFORMANCE TRADEOFFS

The accuracy of GPS as a TSPI data source hinges on a number of factors, foremost of which are the choice of code (P or C/A), systematic error calibration, and the receiver response to signal dynamics. Code selection impacts accuracy in four areas: range resolution, multipath, receiver noise, and uncompensated ionospheric delay. The greater C/A-code chip width would be responsible for larger error contributions from the first three areas. The fourth area, ionospheric delay, can be self-calibrated through the use of a dual frequency correction available only with P-code, since C/A-code is generally unavailable on the L_2 frequency. However, a surveyed reference receiver operated in the differential GPS mode (Fig. 3.1-1) can eliminate all systematic errors with either C/A- or P-code (including ionospheric and tropospheric delay, satellite ephemeris error, and clock error by calibrating them out of the TSPI solution.

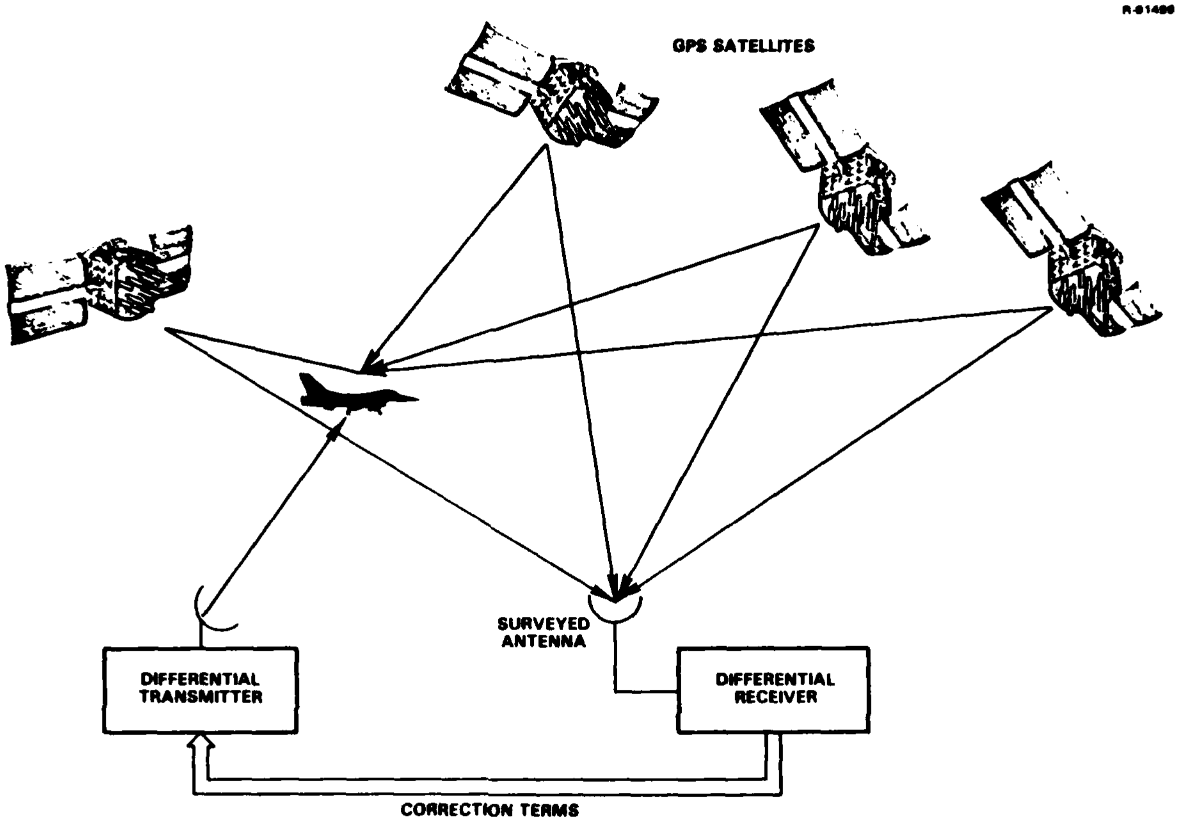

Figure 3.1-1 Differential GPS Concept for Systematic Bias Removal

Based on these considerations, Table 3.1-1 contains an error budget for C/A and P-code with autonomous real-time and real-time differential operation. Of the parameters presented, uncompensated ionospheric delay and multipath are not only key contributors to the error budget, but are also more difficult to quantitatively assess. Sections 3.1.1 and 3.1.2 discuss these terms.

Table 3.1-2 presents the error budget reflecting the anticipated performance after post-mission processing. A key parameter in this table is N, the number of samples used in

TABLE 3.1-1

REAL TIME MEASUREMENT ERROR BUDGET

R-91536

<table>
<tr><th rowspan="2">SEGMENT SOURCE</th><th rowspan="2">ERROR SOURCE</th><th colspan="3">REAL TIME (1σ, ft)</th><th colspan="2">REAL TIME DIFFERENTIAL (1σ, ft)</th></tr>
<tr><th>C/A(L₁)</th><th colspan="2">P(L₁, L₂)</th><th>C/A</th><th>P</th></tr>
<tr><td rowspan="2">SPACE & CONTROL</td><td>SATELLITE EPHEMERIS †</td><td>4.9</td><td colspan="2">4.9</td><td>-</td><td>-</td></tr>
<tr><td>SATELLITE GROUP & CLOCK †</td><td>3.3</td><td colspan="2">3.3</td><td>-</td><td>-</td></tr>
<tr><td rowspan="6">USER</td><td>UNCOMPENSATED TROPOSPHERIC DELAY</td><td>3.3</td><td colspan="2">3.3</td><td>-</td><td>-</td></tr>
<tr><td>UNCOMPENSATED IONOSPHERIC DELAY</td><td>IONO**</td><td>3.3</td><td rowspan="2">3.9</td><td>-</td><td>-</td></tr>
<tr><td>RECEIVER NOISE*</td><td>8.5</td><td>1.3</td><td>8.5</td><td>1.3</td></tr>
<tr><td>MULTIPATH</td><td>10</td><td colspan="2">4</td><td>10</td><td>4</td></tr>
<tr><td>RANGE QUANTIZATION †</td><td>9</td><td colspan="2">0.9</td><td>9</td><td>0.9</td></tr>
<tr><td>RANGE MECHANIZATION ERROR †</td><td>3.3</td><td colspan="2">3.3</td><td>3.3</td><td>3.3</td></tr>
<tr><td></td><td>1σ SYSTEM UERE(ft)</td><td>$(310+IONO^2)^{1/2}$</td><td colspan="2">9.4</td><td>16.3</td><td>4.7</td></tr>
</table>

*$C/N_o(L_1, C/A) = 41$ dB-Hz; $C/N_o(L_1, P) = 38$ dB-Hz; $C/N_o(L_2) = 35$ dB-Hz

**IONO ~ $K/\sin(E^2+20^2)^{1/2}$ WHERE 1.5 ft < K < 15 ft AND E IS ELEVATION ANGLE (deg)

† REFERENCE 2

TABLE 3.1-2

POST MISSION MEASUREMENT ERROR BUDGET

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<table>
<tr><th rowspan="2">SEGMENT SOURCE</th><th rowspan="2">ERROR SOURCES</th><th colspan="3">POST MISSION (1σ, ft)+</th><th colspan="2">POST MISSION DIFFERRENTIAL+</th></tr>
<tr><th>C/A(L_1 ONLY)</th><th colspan="2">P(L_1, L_2)</th><th>C/A</th><th>P</th></tr>
<tr><td>SPACE & CONTROL</td><td>CLOCK, NAVIGATION, SV PERTURBATIONS EPHEMERIS SMOOTHING</td><td>5</td><td colspan="2">5</td><td>-</td><td>-</td></tr>
<tr><td rowspan="6">USER</td><td>UNCOMPENSATED TROPOSPHERIC</td><td>0.7</td><td colspan="2">0.7</td><td>-</td><td>-</td></tr>
<tr><td>UNCOMPENSATED IONOSPHERIC DELAY</td><td>IONO**</td><td>$\frac{3.3}{\sqrt{N}}$</td><td rowspan="2">$\frac{3.9}{\sqrt{N}}$</td><td>-</td><td>-</td></tr>
<tr><td>RECEIVER NOISE*</td><td>$\frac{8.5}{\sqrt{N}}$</td><td>$\frac{1.3}{\sqrt{N}}$</td><td>$\frac{8.5}{\sqrt{N}}$</td><td>$\frac{1.3}{\sqrt{N}}$</td></tr>
<tr><td>MULTIPATH</td><td>$\frac{10}{\sqrt{N}}$</td><td colspan="2">$\frac{4}{\sqrt{N}}$</td><td>$\frac{10}{\sqrt{N}}$</td><td>$\frac{4}{\sqrt{N}}$</td></tr>
<tr><td>OTHER</td><td>1.6</td><td colspan="2">1.6</td><td>-</td><td>-</td></tr>
<tr><td>1σ SYSTEM UERE (ft)</td><td>$(28 + \frac{172}{N} + \mathrm{IONO}^2)^{1/2}$</td><td colspan="2">$(28 + \frac{31}{N})^{1/2}$</td><td>$\frac{13}{\sqrt{N}}$</td><td>$\frac{4.2}{\sqrt{N}}$</td></tr>
</table>

*$C/N_o(L_1, C/A) = 41$ dB-Hz; $C/N_o(L_1, P) = 38$ dB-Hz; $C/N_o(L_2) = 35$ dB-Hz

**IONO ~ K/SIN $(E^2+20^2)^{1/2}$ WHERE $1.5 < K < 15$ ft AND E IS ELEVATION ANGLE (deg)

+N IS NUMBER OF SAMPLES USED IN POST-MISSION SMOOTHING

post-mission smoothing (averaging). An appropriate choice for N must consider the receiver code tracking loop response time and the likelihood of a carrier loop cycle slip. Making N larger will improve system accuracy, as long as no cycle slip occurs. However, if an undetected cycle slip does occur, the averaging process will produce erroneous results. Typically, these considerations would limit the averaging interval to 1-10 sec.

The accuracy of the TSPI solution is a function of both the accuracy of the basic requirements and of the geometry of the satellites relative to the user. This latter factor is actually described by a "dilution-of-precision" (DOP) numerical value summarizing the effect of the geometry. That value, multiplied by the basic measurement error (generally assuming all the measurement errors to be independent and having the same variance) is the user error. For example, HDOP is a measure of the RMS value of the horizontal (two-dimensional) error in a position solution. Other DOP's commonly used are VDOP (for vertical -- one dimensional), PDOP (for position -- three dimensional) and GDOP (geometric -- four dimensional, including time).

The accuracy data presented in Tables 3.1-1 and 3.1-2 are multiplied by typical DOP values (HDOP = 1.5, VDOP = 2.5) to produce the expected GPS equipment accuracies shown in Table 3.1-3 (also shown in this table are the nominal data rates available under various conditions). It is important to note that Table 3.1-3 includes ionospheric delay and multipath effects, but is conditioned on there being no multiple access interference and no uncompensated dynamics.

Multiple access interference is an additional accuracy consideration that becomes an issue primarily when GPS ground

TABLE 3.1-3

GPS ACCURACY* AND DATA RATES

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	REAL-TIME		REAL-TIME DIFFERENTIAL		POST-MISSION§		POST-MISSION DIFFERENTIAL	
	C/A CODE	P CODE	C/A CODE¶	P CODE	C/A CODE	P CODE	C/A CODE¶	P CODE
Position (ft)								
x, y	30	14	25	7	18	9	6	2
z	51	23	41	12	30	14	10	4
Velocity (fps)†								
x, y	0.06-0.65	0.06-0.65	0.06-0.65	0.06-0.65	0.02	0.02	0.02	0.02
z	0.11-1.10	0.11-1.10	0.11-1.10	0.11-1.10	0.03	0.03	0.03	0.03

*Assumes HDOP = 1.5VDOP = 2.5 and no uncompensated user dynamics

†For 1-10 Hz data rates

§With satellite ephemeris and atmospheric delay data from external source, 10 sample average (10 sec)

¶Assumes 10 ft multipath error

NUMBER OF CHANNELS	*HIGH SNR*	*LOW SNR*†
4,5	10-30 Hz	1-4 Hz
2	0.5-1 Hz	0.25-0.5 Hz
1	0.25-0.5 Hz	0.1-0.25 Hz

†Position data only

transmitters (pseudolites) are utilized and the C/A-code is employed. Multiple access interference can manifest itself in one of four ways: front-end saturation, false signal acquisition, signal-to-noise degradation, and signal capture. Each of these is discussed in detail in Section 3.1.3.

Irrespective of code selection, uncompensated dynamics can induce measurement errors through dynamic response lag and/or unmodeled higher-order terms (acceleration, jerk ...) in the TSPI data. One solution to the lag problem is to implement a third-order signal tracking loop in the receiver which will reduce errors due to dynamics, albeit, at the cost of a somewhat reduced data rate (from 30 to 20 Hz). One and two channel receivers will react even more adversely to the unmodeled higher-order dynamics than a four or five channel receiver since a sequential solution is available less often and position data must be extrapolated for longer periods of time.

An all-encompassing solution to the problem of dynamics is to utilize a relatively low quality IMU for carrier loop aiding. This solution (if volume and cost permit) offers three additional advantages: data may be provided at a higher rate; L-band noise may be accommodated with less accuracy degradation; and satellite reacquisition following extended signal loss may be accomplished more easily since vehicle position and velocity are known more precisely for a longer period of time after signal loss.

In addition to accuracy considerations, the time that it takes to obtain a GPS navigation solution following receiver turn-on is an important parameter. This time is referred to as the time-to-first-fix (TTFF). A detailed discussion of TTFF is provided in Appendix A and summarized in Section 3.1.4.

The remainder of this section deals with several major error budget contributors in more detail. For readers not interested in the specifics of GPS performance, this material can be omitted.

3.1.1 Multipath (Ref. 1)

Multipath signals can have a significant amplitude relative to the desired direct ray. The problem can be particularly severe when the user is over water. Referring to Fig. 3.1-2, the dependence of multipath differential delay, ΔT, on elevation angle (θ) and user altitude (h) is given by

$$\Delta T \sim \frac{2h}{c} \sin\theta \qquad (3.1\text{-}1)$$

where c is the speed of light.

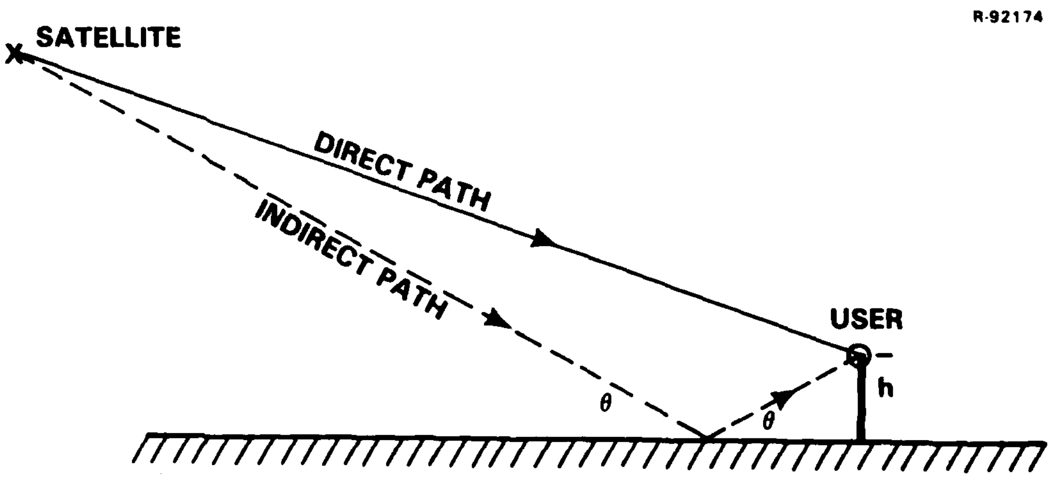

Figure 3.1-2 Multipath Geometry

There are two cases that need to be considered. If the delay difference is greater than 1.5 chips (1.5 μsec for

C/A-code, 150 nsec for P-code) and the user is already tracking the desired signal, then multipath looks like a repeater jammer which is discriminated against by the steep autocorrelation peak of the code. In fact, the delayed signal, with some qualification, affects the receiver performance much like a noise signal with equivalent noise spectral density. For the P-code, the signal structure provides 71.8 dB-Hz of discrimination against this signal (whereas the C/A-code offers 61.8 dB-Hz) and thus, the multipath signal has minimal effect.

If the delay difference is less than 1.5 chips, however, the effect of multipath on receiver accuracy can be significant. Figure 3.1-2 illustrates the envelope for the average C/A-code multipath tracking error for three multipath signal-to-desired signal amplitude ratios of 0.2, 0.6, and 1.0 for the case where the receiver is initially tracking the desired signal.* A similar set of curves exist for the P-code. (To a first approximation, the curves are the same with only a scale change -- the scales of both the abscissa and the ordinate shown in Fig. 3.1-3 would be multiplied by a factor of 0.1). The C/A code multipath value of 10 ft shown in Table 3.1-1 and 3.1-2 was derived from Fig. 3.1-3 assuming an airframe multipath delay of 10 ft and a moderately strong multipath condition. (The P-code error of 4 ft is based on an analogous curve.)

Although the actual effect of multipath on tracking accuracy is highly scenario dependent, nonetheless, it can be unequivically stated that the C/A-code is more susceptible to multipath-induced errors than the P-code for two reasons. First, flight geometries are more likely to support detrimental C/A multipath as illustrated in Table 3.1-4. The data shows

*As with any multipath phenomena, the actual effect in a specific instance depends on the multipath and direct ray phase delay relationships.

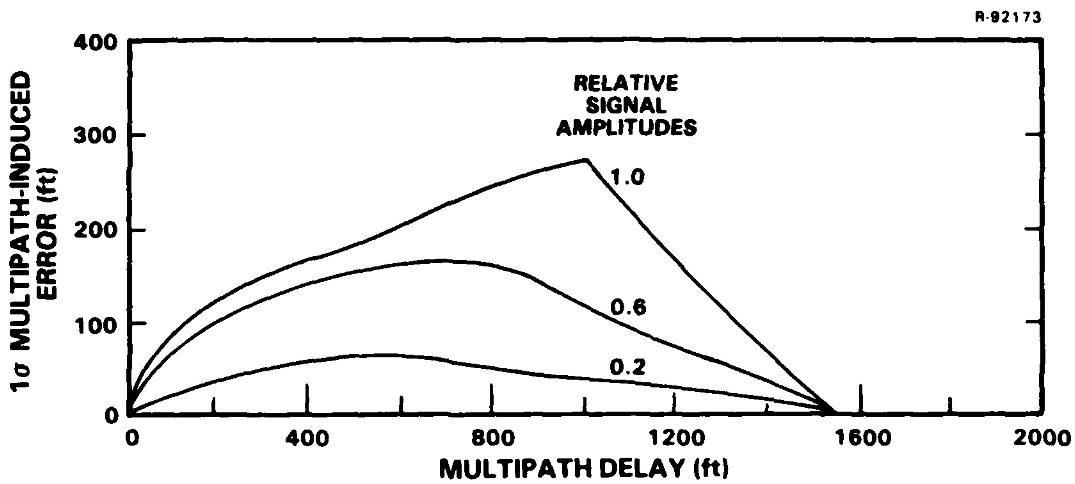

Figure 3.1-3 Expected C/A-Code Tracking Error Due to Multipath

TABLE 3.1-4

CODE SUSCEPTIBILITY TO MULTIPATH

ELEVATION ANGLE	MAXIMUM USER HEIGHT FOR MULTIPATH	
	P	C/A
10°	260 m	2600 m
90°	45 m	450 m

that multipath-induced P-code errors are rather unlikely without the combination of low altitude and low elevation angle. Second, maximum C/A-code errors can be ten times greater than maximum P-code errors, while for a given multipath delay, the C/A-code error is likely to be 2 to 3 times greater than the P-code error.

3.1.2 Ionospheric Delay (Ref. 2)

The presence of a finite free-electron transmission medium produces a GPS PN code delay with a resulting range bias

error. The magnitude of the delay depends upon the total free electron content along the line-of-sight between the satellite and the user.

The two primary statistical uncertainties for any model of the ionospheric delay are variations in electron content and geometric obliquity. When the solar cycle is near its maximum value, the mid-day electron content can be as large as 10^{18} electrons/meter^2 at mid-latitude, whereas average values of daytime electron content can be an order-of-magnitude smaller, with a minimum value two orders-of-magnitude smaller. These uncertainties significantly impact the accuracy of any ionospheric delay model. Fortunately, to avoid the inherent inaccuracy of employing an apriori estimation model of the delay, real-time dual frequency measurements can be utilized, if available, to provide ionospheric compensation.

An overview of the dual frequency approach is discussed below. This is followed by a brief description of an ionospheric delay model, for those cases where dual frequency measurements are not (cannot) be utilized. It should be emphasized that the differential GPS mode depicted in Fig. 3.1-1 offers a third, and most effective, means of minimizing ionospheric delay-related errors.

Dual Frequency Measurement Technique Error - GPS users requiring high accuracy navigation can make use of real time dual frequency (L_1 and L_2) measurements available only with the P-code to determine ionospheric delay. The resultant accuracy of this approach is determined by the measurement noise inherent in each code channel pseudo-range estimate.

The basis for the two frequency method of correcting for ionospheric group delay is that the delay error (ΔR) is an exactly deterministic function of frequency

$$\Delta R = \frac{S}{F^2} \tag{3.1-2}$$

where

S is a constant scale factor

F is the carrier frequency (L_1 or L_2)

In order to perform dual frequency ionospheric compensation, the pseudo-range measurements from the L_1 and L_2 channels (denotes ρ_1 and ρ_2), respectively, are first differenced,

$$\Delta\rho = \rho_2 - \rho_1 \tag{3.1-3}$$

and then the unbiased estimate for ΔR is formed by the operation

$$\Delta\hat{R} = \left[\frac{L_2^2}{L_1^2 - L_2^2}\right] \Delta\rho \tag{3.1-4}$$

where L_1 and L_2 are the GPS carrier frequencies. Since the L_1 and L_2 receiver noise terms are uncorrelated, the variance of the noise in the measurement of $\Delta\hat{R}$ is simply

$$\sigma^2_{\Delta\hat{R}} = \left[\frac{L_2^2}{L_1^2 - L_2^2}\right]^2 (\sigma_1^2 + \sigma_2^2) \tag{3.1-5}$$

where σ_1^2 and σ_2^2 are the variance of the L_1 and L_2 receiver channel noise terms, respectively.

After compensation for the ionospheric delay on L_1, the variance of the residual measurement noise, denoted $\sigma^2_{\hat{\rho}_1}$, given by

$$\sigma^{2\prime}_{\rho_1} = \frac{L_1^4\,\sigma^2_{\rho_1} + L_2^4\,\sigma^2_{\rho_2}}{(L_1^2 - L_2^2)^2} \qquad (3.1\text{-}6)$$

With the assumption of equal noise variances for both L_1 and L_2, the dual frequency measurement error is

$$\sigma'_{\rho_1} \sim 3\,\sigma_{\rho_1} \qquad (3.1\text{-}7)$$

Thus, the dual frequency mechanization technique changes the ionospheric bias term into a zero-mean noise-like measurement error with the net effect that the standard deviation of the receiver noise is increased. Note, in most cases the noise-like dual frequency error can be reduced by multiple measurement averaging.

Apriori Algorithm Estimation - C/A-class users cannot employ dual frequency ionospheric compensation (C/A is generally not available on L_2), but rather must utilize apriori mathematical ionospheric models. (Unless a reference receiver is employed in a differential mode to remove the effect of ionospheric refraction.) These apriori models must consider the factors which influence the values for electron content and geometric obliquity; e.g., diurnal variation, latitude dependence, seasonal variation, and solar cycle variations.

Present ionospheric models, even with near real-time parametric data, reduce ionospheric delay error only by 50 to 75%. The residual error (ΔL) resulting from such modeling is of the form,

$$\Delta L = \Delta K \frac{1}{\sin(E^2+20^2)^{\frac{1}{2}}} \qquad (3.1\text{-}8)$$

where

E is the elevation angle (deg)

ΔK is the fractional value of reduced ionospheric delay (typically, $0.5m \leq \Delta K < 5m$)

3.1.3 Multiple Access Interference

The use of ground transmitters (pseudolites) for TSPI application would introduce a new class of potential problems, namely multiple access interference, which must be addressed. In particular, proximity to a ground transmitter (GT) may result in one of four deleterious effects:

- Receiver Front-End Saturation
- False Acquisition
- Signal-to-Noise Degradation
- Signal Capture

As discussed below, these effects tend to be more severe for C/A-code than for P-code.

In general, these problems can be minimized by employing GT power management and using many GTs to cover a given test range (to account for the reduction in GT power level). However, this potential solution has several drawbacks:

- The technique is not feasible for the case of many test vehicles
- GTs are expensive
- Part of the signal capture problem is unaffected by a uniform reduction in GT power level.

Hence, for these reasons, it is necessary to assess the severity of multiple access interference.

Receiver front-end saturation can be effectively countered by employing variable receiver front-end attenuators to reduce the near-far problem and thus improve the receiver's dynamic range.

False acquisition occurs when the reference code (in the receiver) for a selected satellite (or GT) cross-correlates with a non-desired, stronger signal from a near-by GT. In practice, the problem will not occur for the P-code because the cross-correlation sidelobe is -50 dB relative to the peak of the code autocorrelation function. For the C/A-code, however, the crosscorrelation peak is ~-22 dB, and thus, false acquisition is more possible. Nonetheless, if a false acquisition occurs, it can be detected and the acquisition process reinitiated. Hence, false acquisition is not a serious problem.

The two remaining issues - signal-to-noise degradation and signal capture -- are more complex problems which will require some rudimentary analyses to properly assess their importance. Figure 3.1-4 illustrates a simplistic model of a receiver which is tracking the desired signal, S_D, denoted

$$S_D = S_1 e^{j\omega_1 t} \tag{3.1-9}$$

while being interfered with by a secondary undesired signal, S_u, with similar signal structure,

$$S_u = S_2 e^{j\omega_2 t} \tag{3.1-10}$$

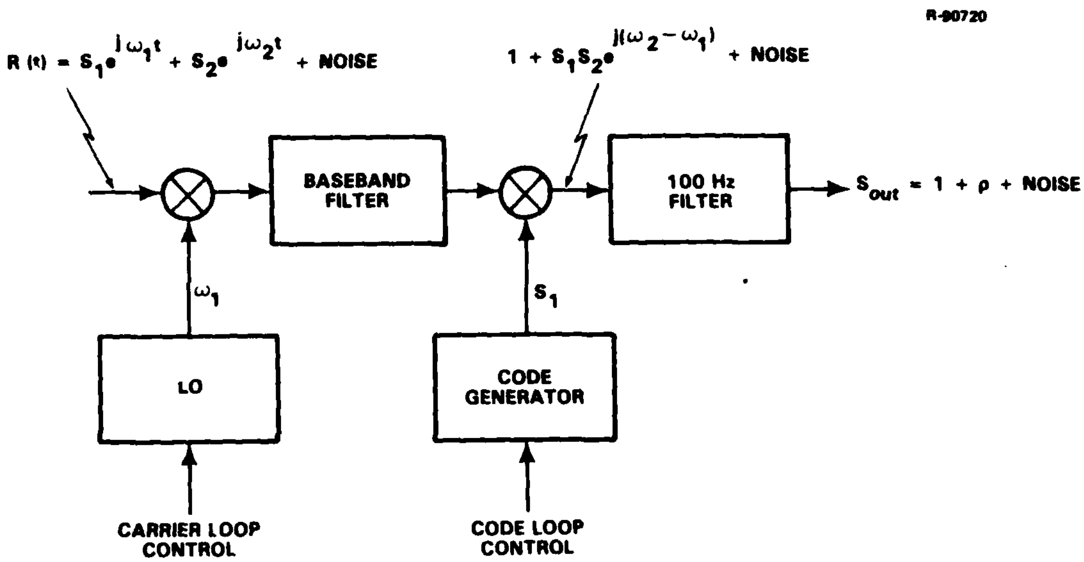

Figure 3.1-4 Multiple Access Interference in User Receiver

Note that following filtering, the output signal, S_{out}, is denoted

$$S_{out} \approx 1 + \rho + \text{noise} \qquad (3.1\text{-}11)$$

In most cases the undesired signal appears noise-like and ρ is basically an additive noise term. As such, its effect is diminished by the spread spectrum processing gain of the particular code being tracked (i.e., ~70 dB-Hz for the P-code, ~60 dB-Hz for the C/A-code). Nonetheless, if the amplitude, S_2, is large compared to the amplitude, S_1 (because of proximity to the S_u signal source) then, in spite of the inherent interference rejection provided by the GPS codes, the increase in the noise level will result in a degradation in tracking accuracy.

In certain cases (discussed below), the undesired signal appears signal-like. Under these circumstances, ρ is a

measure of relative (effective) interferer strength. If $\rho << 1$ and negative, signal-like interference can result in a reduction in tracking accuracy by degrading the signal level. A more serious problem can occur if ρ is comparable or large relative to the value 1. In this case the receiver tracking loops could actually be captured by the undesired signal. It should be noted that although the occurrence of the event could be detected, successful reacquisition of the desired signal is unlikely as long as the situation which led to signal capture in the first place persists.

The undesired signal will appear signal-like when its contribution to the output of the 100 Hz low pass filter (10 msec integration) shown in Fig. 3.1-4 stays essentially constant for many code loop time constants. This cannot happen for the P-code because of its low cross-correlation peaks. For the C/A-code, however, not only is this situation possible, but likely. In particular, it has been shown that the likelihood of aligning with a cross-correlation peak (-22 dB for C/A-code) is 0.25. Furthermore, if the differential doppler (denoted $\omega_2-\omega_1$ in Fig. 3.1-4) is small relative to the low pass filter bandwidth (100 Hz) -- quite likely in GT applications -- a particular cross-correlation alignment can last for many code loop time constants. For example, a differential doppler <100 Hz (corresponding to a differential velocity of 60 ft/sec) will keep the C/A-code aligned for at least 15 sec, which compares with a typical loop response time of 1 sec.

In addition, for the C/A-code, not only is it likely that the undesired signal appears signal-like, but its relative amplitude can be quite large for GT applications. Even though the C/A-code cross-correlation peak is no larger than -22 dB, this gain difference can be easily made up if the user is sufficiently close to the undesired signal source. When this happens, signal capture is likely to occur.

In order to minimize the risk of GT-induced accuracy degradation or capture, it would be necessary to establish "exclusion regions" about each GT, in which test articles would not operate. The size of the exclusion region about a GT which results when one considers the following four scenarios has been studied in detail:

- GT capture of another GT signal
- GT capture of satellite (SV) signal
- GT degradation in GT signal-to-noise ratio
- GT degradation in satellite (SV) signal-to-noise ratio.

Each of these cases was considered for both the P-code and the C/A-code. The mathematical details of the analyses are presented in Ref. 3 and the results are summarized in Table 3.1-5.

The exclusion regions were determined assuming a maximum test range distance (R_{max}) of 50 nm (for which a given signal-to-noise ratio was required, 30 or 40 dB-Hz as shown in the table). The results in the table scale linearly with R_{max}. For each of the three cases presented, the shaded number in each row indicates the most stringent requirement on the exclusion region. For example, for the P-code and a C/N_o of 30 dB-Hz at R_{max}, then possible GT degradation in signal-to-noise level imposes an exclusion region radius of 0.5 nm about each GT.

The results shown in the table clearly indicate that for comparable receiver tracking accuracy, P-code imposes a considerably smaller exclusion region than C/A-code (0.5 nm vs 16 nm). Note if the accuracy requirement is relaxed, i.e., if a 10 dB degradation in C/N_o is acceptable, (to 30 dB-Hz)

TABLE 3.1-5

MULTIPLE ACCESS INTERFERENCE EXCLUSION REGION SUMMARY

R-91533

	CASE		EXCLUSION REGION, R_{MIN} (nm)*			
			SIGNAL CAPTURE†		DEGRADATION IN C/N_o	
	CODE	C/N_o (dB-Hz)	GT SIGNAL CAPTURE	SV SIGNAL CAPTURE	GT SIGNAL DEGRADATION	SV SIGNAL DEGRADATION
COMPARABLE RECEIVER TRACKING PERFORMANCE	P	30	-	-	0.5	0.16
	C/A	40	6.8	8	5	16
	C/A	30	6.8	2.5	1.6	0.5

*R_{MAX} = 50 nm

†6 dB MARGIN TO ACCOUNT FOR ANTENNA FADE

then the exclusion region for C/A-code reduces to 6.8 nm if signal capture is considered and 1.6 nm if signal capture is not. This example clearly highlights:

1) The relationship between signal-to-noise requirement and test range utilization constraints

2) The need to accurately derive an error budget so that the impact of a signal-to-noise reduction on resultant accuracy can be properly assessed

3) The need for empirical, i.e., field test, data to substantiate the signal capture analysis results.

Without an accurate error budget and signal capture field test data, use of the C/A-code in a GT environment appears to impose unacceptable test range constraints.

3.1.4 Time-to-First-Fix

Before a ranging receiver can close-loop track the pseudo-random noise (PN) code, it must first acquire the code sequence -- the term "acquisition" denotes the open-loop synchronization of carrier and code phases by the user. Hence, the acquisition procedure is the first step in establishing a TSPI fix. After close-loop tracking is achieved, the user demodulates the GPS navigation data, which is then combined with pseudo-range and delta range measurements in an appropriate algorithm to compute the TSPI fix. The time required to perform this entire operation is denoted the time-to-first-fix (TTFF), and is composed of the acquisition time, the data demodulation time, tracking time, and the navigation fix time.

This entire TTFF process is described in detail in Appendix A. P-code TTFF statistics using conventional code

search techniques is summarized in Table 3.1-6 for several starting conditions, with the warm start condition numbers being typical of the normal P-code acquisition process. C/A-code only operation would basically halve the "normal acquisition numbers," leaving all other numbers essentially unaltered. (Obviously, direct reacquisition is not relevant for the C/A code.) Advanced code search techniques exploiting VLSI technology have the potential for significantly reducing the indicated TTFF times.

It should be noted that the table does not include electronic and oscillator warm up times. In addition, the table assumes single frequency operation; dual frequency operation adds 1 to 4 sec, depending on the number of channels. If a fifth channel were available, not only could the initial acquisition process be speeded up, but satellite switching could be accomplished in basically zero time if the channel were already tracking a fifth satellite.

3.2 INSTRUMENTATION PORT

The possible use of operational GPS receivers to support TSPI applications is dependent not only upon data availability (through a data bus or special wiring) but upon the capability of the instrumentation port to provide the desired data at useful rates as well. An examination of the GPS Interface Control document (Ref. 4) showed that there are three types of data available from the instrumentation port; "Operational/Test" data, "Host Vehicle" data, and "Generic" data.

Operational/Test data blocks are standardized among vendors and contain information which includes motion and navigation parameters, mother/daughter initialization data and

TABLE 3.1-6

TYPICAL TTFF FOR P-CODE, SINGLE CHANNEL

R-87428

CONDITIONS	ICE COLD START	COLD START	WARM START*	NORMAL REACQUISITION	DIRECT REACQUISITION
ALMANAC IN STORAGE	NO	YES	YES	YES	YES
PRECISION EPHEMERIDES AND CLOCK CORRECTIONS IN STORAGE	NO	NO	NO	YES	YES
USER CLOCK ERROR	∞	10 min	10 min	100 μsec	1 μsec
USER POSITION ERROR	∞	∞	60 nmi	5 nmi	1000 ft
USER VELOCITY ERROR	300 fps	300 fps	15 fps	15 fps	15 fps
SET TYPE	TTFF				
1 CHANNEL	39.1 min	10.5 min	4.3 min	45 sec	13 sec
2 CHANNELS	19.6 min	5.3 min	2.2 min	23 sec	7 sec
4 CHANNELS	9.8 min	2.6 min	1.1 min	12 sec	4 sec

*NORMAL ACQUISITION, I.E., C/A TO P HANDOVER

weapon delivery data. Host Vehicle data blocks are also standardized among vendors but are vehicle-dependent in content. These data may include motion and navigation parameters, filter covariances (for some host vehicles) and sensor-related parameters. Generic data blocks typically consist of navigation- and receiver-oriented information such as filter and GPS measurement data, respectively, plus data associated with onboard sensors and weapon delivery tests. These Generic blocks are not standarized among vendors, which may limit their usefulness for TSPI applications where pre-planned data sequences are desirable (see below).

Basic TSPI data transmitted as part of the Operational/Test data is contained in the "Data Capture Block" (see Table 3.2-1). This data block, consisting of 64 - 16 bit words, is only available at data rates of 2 Hz or less from the instrumentation port of current and planned GPS Joint Program Office-sponsored receivers. Other data blocks are typically available at a rate of 1 Hz or less. The present constraints on the data transfer rates out of the instrumentation port are the use of an onboard digital recorder (which could support the output of Data Capture Blocks at a 10-20 Hz rate, but may saturate if other blocks are added), and the data command protocol which responds to requests for specific data blocks.

If onboard digital recording of the instrumentation port outputs can either be limited to Data Capture Blocks or avoided completely, a software modification to transmit a pre-loaded sequence of data blocks to obtain data rates at the full capacity of the receiver appears feasible (Ref. 5) since the port can support data transfer rates up to 77k BAUD (see Table 3.2-2 for examples of possible data sequences and the data transfer rates required for various GPS receiver data rates.)

TABLE 3.2-1

CONTENTS OF BASIC DATA CAPTURE BLOCK

DATA ITEM	NO. OF VARIABLES	DATA TYPE	NO. OF WORDS	UNITS
GPS Time	1	Double Precision Floating Point	4	Seconds
Cut Time	1	Double Precision Floating Point	4	Seconds
Δ From GPS Time	1	Integer	1	10 Milliseconds
Time Mark Counter	1	Integer	1	NA
Position (Lat, Lon)	2	Floating Point	4	Radians
Position (x,y,z)	3	Floating Point	6	Meters
Altitude (MSL & Absolute)	2	Floating Point	4	Meters
Velocity (E,N,Up)	3	Floating Point	6	Meters/Second
Acceleration (E,N,Up)	3	Floating Point	6	Meters/Sec/Sec
Attitude (Pitch, Roll)	2	Floating Point	4	Radians
True Heading	1	Floating Point	2	Radians
Magnetic Variation	1	Floating Point	2	Radians
Measurement Channel Status	4	Binary	10	NA
Position Error Std. Dev. (N,E,Up)	3	Floating Point	6	NA
RSS (N,E,Up) Pos. Error Std. Dev.	1	Floating Point	2	Meters
Equipment Configuration	1	Binary	2	NA

TABLE 3.2-2

GPS DATA TRANSFER REQUIREMENTS SUMMARY

PRE-PROGRAMMED SEQUENCES	PARAMETERS	DATA TRANSFER RATE (Hz) GPS DATA RATE (Hz) 0.25	0.50	1	2	10	20
Minimal GPS	Time, Pos, Vel	64	128	256	512	2560	5120
Data Capture Block	Time, Pos, Vel, Accel, Attitude, Altitude, Status, Config.	256	512	1024	2048	10240	20480
Test Data Blocks: ● Data Capture ● Midcourse Command* ● Time Mark ● Midcourse Ephemerides* ● Weapon Delivery† ● Selected Target† ● HV Transparent	 Same as Above Number of Ephemerides Available Same as Data Capture Ephemerides Predicted Bomb Impact Data Waypoints to Target Host Vehicle Data (Unspecified)	256	512	1024	2048-7299	10240-12419	20480-22275
Test Data Blocks + NAV Oriented Blocks + Receiver Oriented Blocks	Same as Above NAV Filter Inputs, Outputs Residuals Receiver Measurements and Aiding, Iono, Control, Almanac, Calibration Data	576**	1152**	2304**	4600-9900**	23000-25000**	46000-48000**
Host Vehicle I/O	Variable	Variable Block Size††					

*For missile receiver initialization
†For GPS computed weapon delivery
**Numbers are approximated (manufacturer/dependent) assuming NAV and receiver oriented blocks add total of 100 words
††Approximately 5 kbps at 10 Hz for F-16.

3.3 HARDWARE PROJECTIONS (SIZE, WEIGHT, POWER)

The utility of GPS receivers and translators for many TSPI applications may be partially constrained by the volume the equipments occupy (assuming repackaging can accomodate envelope constraints) and, particularly for small unmanned vehicles, by power requirements and weight. Weight and volume are also significant factors for TSPI receivers carried by troops in large-scale excerises since the resulting package (including communications) cannot inhibit normal movement to any degree. In order to deduce the impact of employing GPS equipment in the test range environment, a survey was conducted through discussions with industry personnel and by examining documentation supplied by the Tri-service Steering Committee to establish equipment parameter projections which reflect potential technological growth relative to the current baselines displayed in Table 3.3-1.

TABLE 3.3-1
TYPICAL CURRENT GPS EQUIPMENT PARAMETERS

EQUIPMENT PARAMETERS	P-CODE RECEIVERS*			C/A CODE TRANSLATORS	
	ONE CHANNEL	TWO CHANNEL	FIVE CHANNEL	LOW POWER (1W)	HIGH POWER (50W)
Size (in^3)	450	600	800	30	200
Weight (lbs)	13	23	43	3	14
Power (W)	13	100	140	50	110

*Flexible Modular Interface Excluded.

The results of the survey are summarized in Figs. 3.3-1 and 3.3-2 for GPS receivers. These plots indicate a projected reduction in receiver volume and weight of approximately 30 percent and 15 percent, respectively, over a 5 year period.

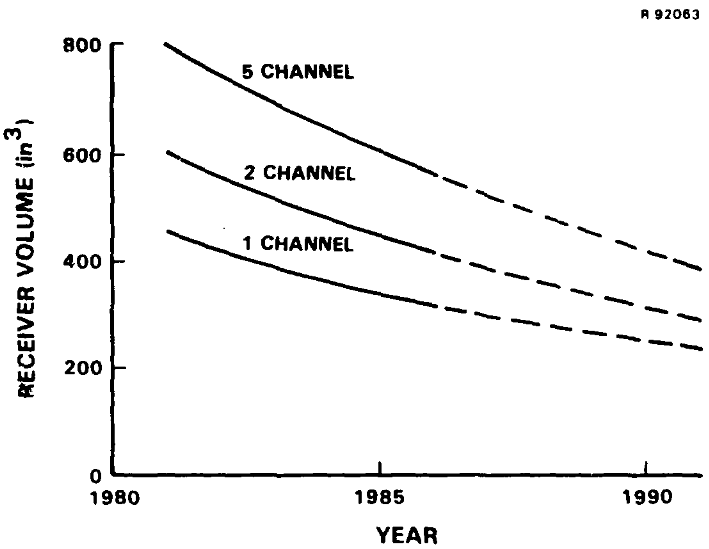

Figure 3.3-1 Projected Receiver Volume (P-, C/A-Code)

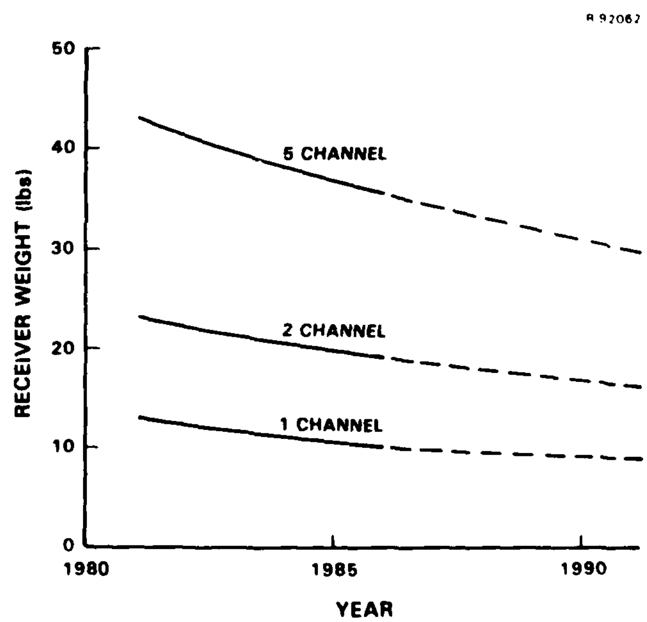

Figure 3.3-2 Projected Receiver Weight (P-, C/A-Code)

Although projections of receiver power reductions were not available, some reductions are anticipated. Translators are expected to exhibit a similar reduction in volume (on a percentage basis) as that shown for receivers, although weight and power reduction may be greater (on the order of 20 to 30 percent over a 5 year period). It should be noted that all-digital receiver mechanizations could result in significantly greater reductions in volume than that indicated in Fig. 3.3-1 for the late 1980's.

At this point in the discussion of GPS hardware projections, it is instructive to illustrate the use of the projection data by comparing the volume required by a GPS receiver with the projected volume availability of several instrumentation pods (see Table 3.3-2). The data shows that by 1985, any of the P-code receivers or a C/A-code translator, could fit in the NCP or APX-82 pod, even with an inertial system added. (A Low Cost Inertial Guidance System (LCIGS) displaces approximately 400 in^3.)

For the ACMI pod, however, a translator or two channel receiver appears to be the best near-term option for high and medium dynamic applications, respectively. An option incorporated into the recommended GPS instrumentation equipment family (Chapter 13), would be to integrate a 5-channel receiver <u>without the data processor</u> into the ACMI pod. This receiver would output pseudo-range and delta range measurements rather than position and velocity fixes. In the late 1980's it is anticipated that complete 5 channel, digital receiver designs may be accomodated in the ACMI pod (without an IMU). In the case of the AIS pod, however, the translator seems to be the only practical TSPI solution from a volume perspective.

TABLE 3.3-2
PROJECTED AVAILABLE SPACE IN INSTRUMENTATION PODS

POD TYPE	LENGTH (in)	DIAMETER (in)	AVAILABLE SPACE	
			CURRENT (in^3)	PROJECTED (in^3)
AIS	108	5	0	200-300*
NCP	122	5	1270	1270†
ACMI	141	5	225	450*
RMS/SCORE**	131	5	0	N.A.
APX-82††	57	8.5	1506	1506

*With redesign (reconfiguration and miniaturization).

†Nellis concept pod with transponder only.

**Replaced by ACMI pod.

††Helicopter pod.

3.4 TSPI CONFIGURATIONS

GPS receivers and translators will be incorporated into TSPI configurations which are designed to support the required level of accuracy, transmit the data to a command and control (C^2) center for range safety and test monitoring purposes, and provide data storage for post-mission processing. Because of the diversity of test articles (with respect to size and dynamics) and scenarios encountered (local and remote), the configurations will, by necessity, differ. Four configuration have been devised which, with optional variations, will satisfy most needs of the test and training community. Each incorporates a GPS receiver or translator as the primary TSPI source as well as the communications needed for data transfer to a control center.

The first configuration (shown in Fig. 3.4-1) is suitable for applications where the GPS receiver and communication system is wholly contained within the vehicle, a pod or in a man-transportable pack. It includes an option for IMU aiding of the receiver, where required by vehicle dynamics or data rate considerations. Included in the configuration is a two-way communication package for transmitting TSPI data to and receiving commands from the control center. For scenarios where relays are needed due to line-of-sight (LOS) restrictions (such as for low flying cruise missiles or over-the-horizon aircraft), a relay communication system has been identified. Finally, the control center itself is depicted as consisting of a TSPI and C^2 data processor, a communications system and a differential GPS station. The latter is shown as a switchable option to make the figure more generally applicable to both localized scenarios, where differential GPS has an accuracy payoff, and scenarios where either the additional accuracy is not needed or remoteness from a surveyed site precludes the use of the differential concept.

The second GPS configuration applies to aircraft-borne pod-based TSPI systems which utilize an onboard, operational GPS receiver. It is assumed that the TSPI data will be made available to the aircraft pod through a 1553 data bus or special cabling run. An IMU, shown as residing onboard the aircraft, should be available to provide aiding if needed. The remainder of the configuration (beyond the 1553 bus) is identical to that shown in Fig. 3.4-2.

The third configuration, developed for translators, has wide applicability to a variety of vehicles ranging from large and small missiles, drones and aircraft (see Fig. 3.4-3). Provision has been made for optional IMU aiding of the translator signal receiver as well as the optional digitizing and

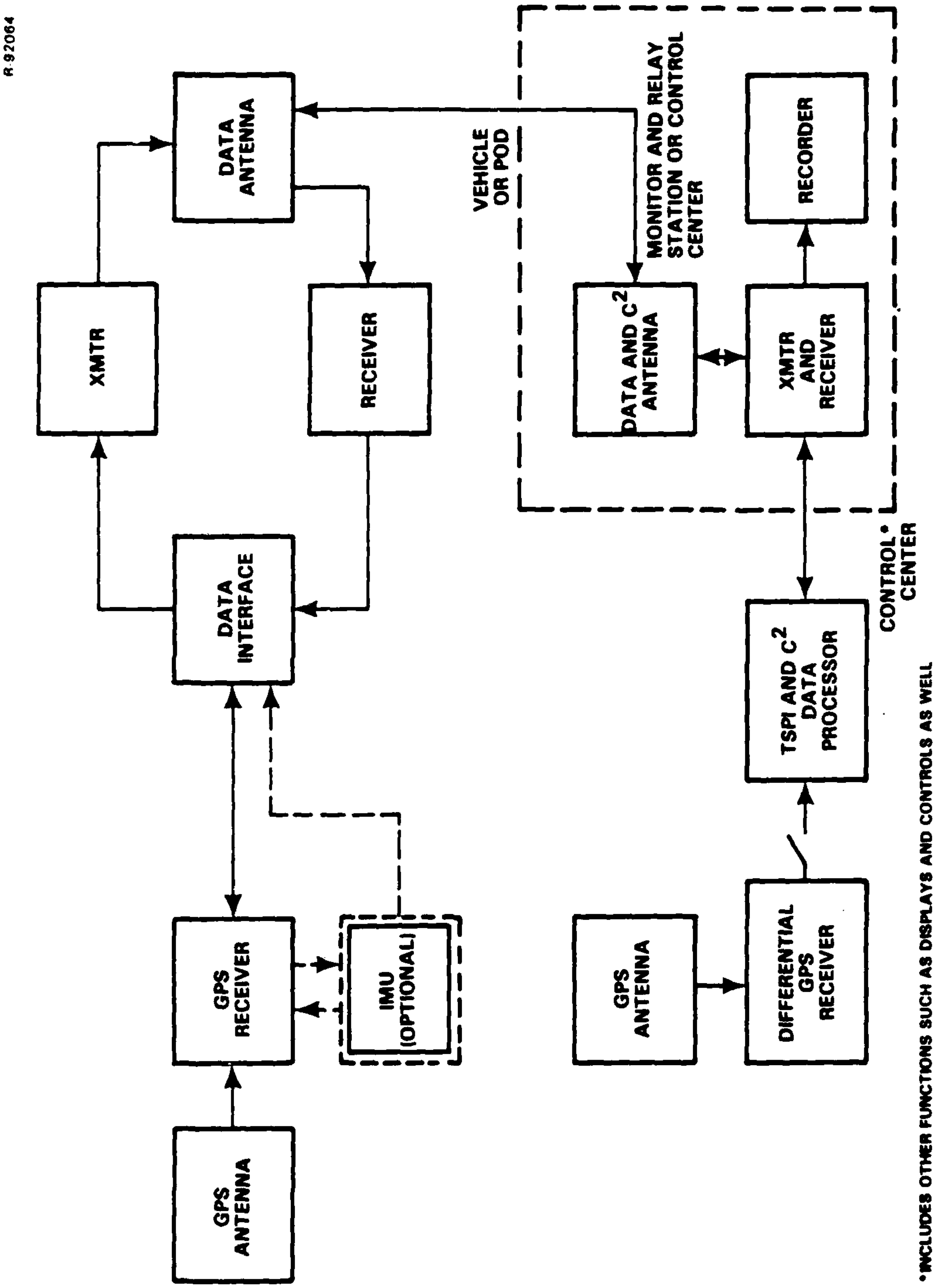

Figure 3.4-1 Onboard or Pod Receiver (Configuration 1)

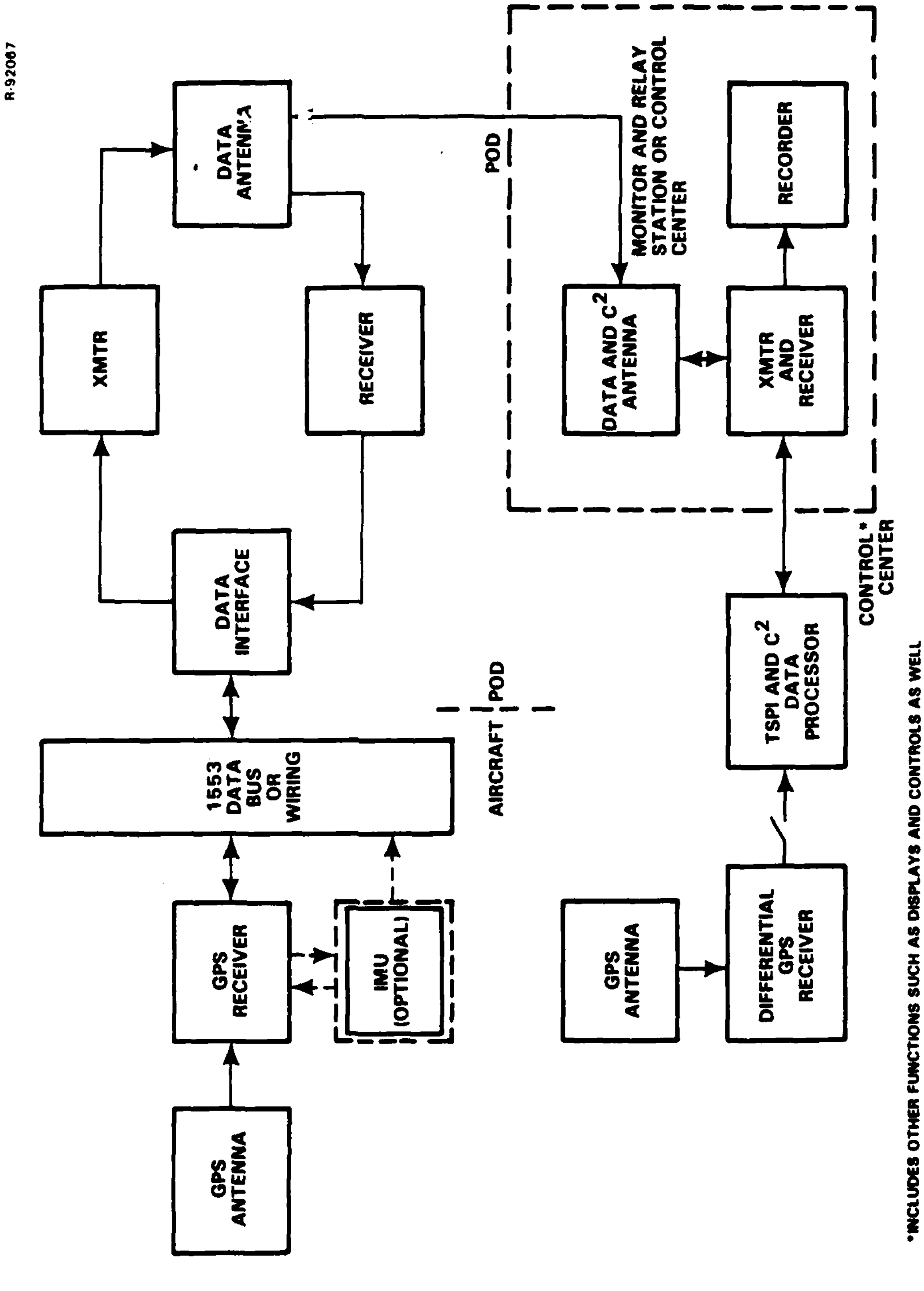

Figure 3.4-2 Pod Plus Operational GPS Receiver (Configuration 2)

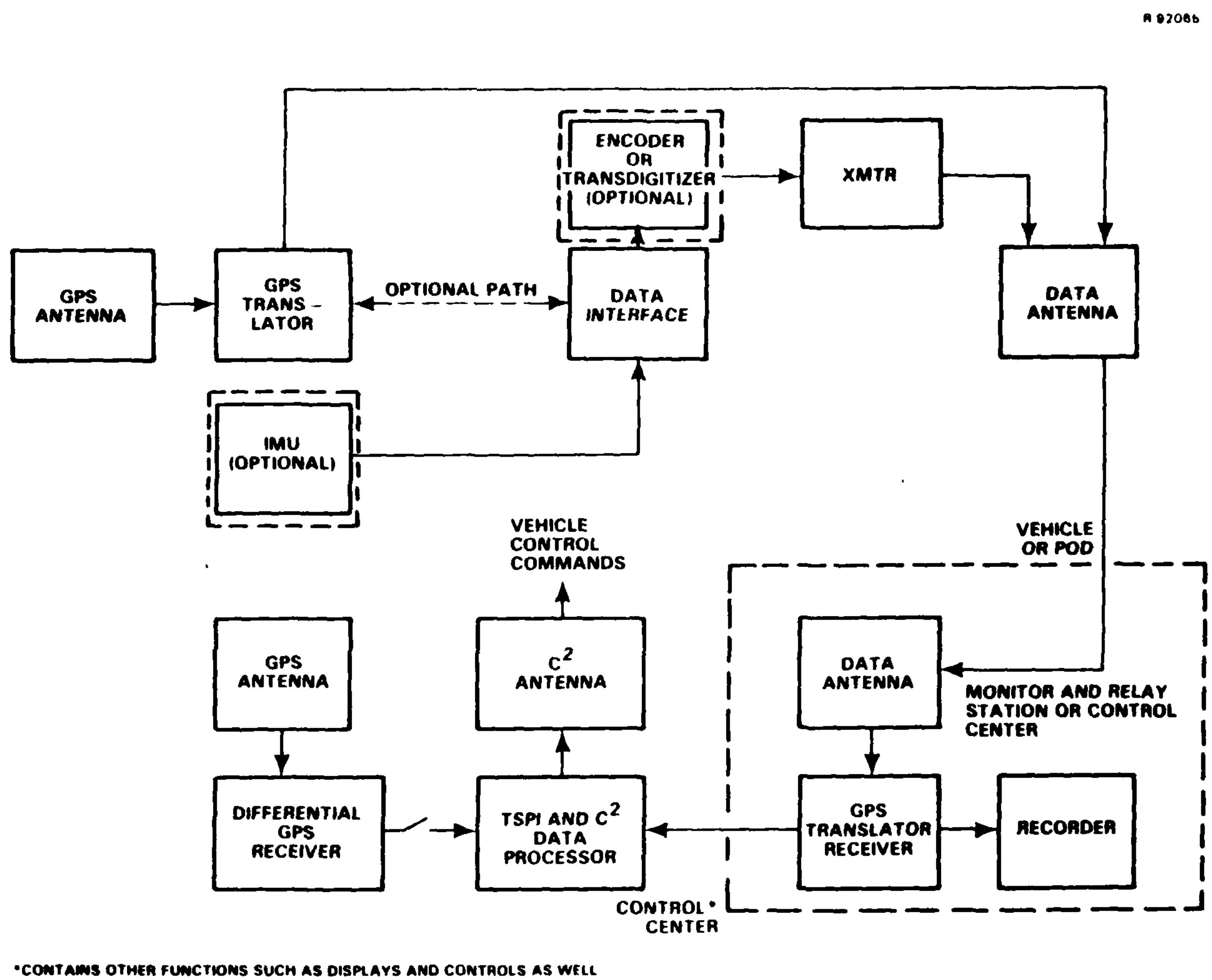

Figure 3.4-3 Onboard or Pod Translator (Configuration 3)

encoding (or encryption) of the translator's output signal. The onboard data antennas will transmit either the frequency-translated signals directly from the translator or the digitized data. A separate C^2 antenna is shown for issuing commands to the test article; not shown (for the sake or clarity) is a separate onboard communication system for receiving vehicle commands.

Figure 3.4-4 shows a special configuration for ships. It is similar to the second configuration in that an operational GPS set is used as a TSPI source, but differs sufficiently to specify a separate configuration; i.e., no IMU or pod interface. Finally, the differential GPS station was eliminated because it would not add any needed capability.

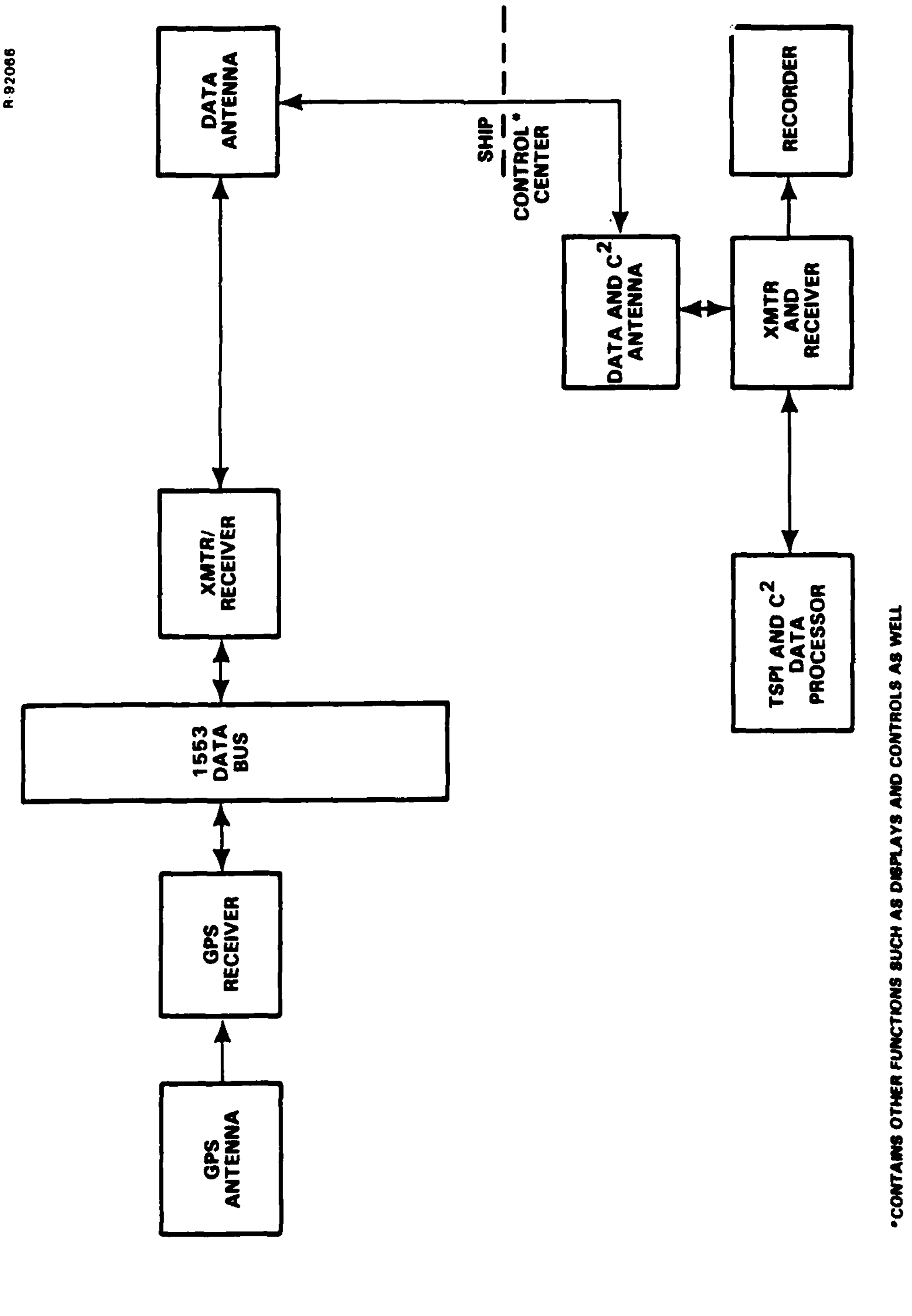

Figure 3.4-4 Operational Ship GPS Receiver (Configuration 4)

4. GPS COST BENEFIT EVALUATION METHODOLOGY

The potential cost benefits of GPS for test and training applications were assessed in this study through a comparative evaluation of GPS- and non-GPS-based instrumentation concepts for eight generic test ranges which were patterned after 20 major DOD ranges. Both near-term (1985-1987) and far-term (1988+) transitions to GPS were considered with each system option required to support the basic TSPI-related functions of data generation, collection, and command and control for each specified test arena and time frame. Near-term generic range requirements tended to be relatively consistent with existing rational range capabilities (with the exception of altitude and velocity accuracy); however, far-term requirements tended to be more stringent to encompass service-derived requirements for the 1988+ time frame.

During the evaluation of GPS benefits to each generic range, effectiveness was assessed by looking at near- and far-term options independently so that a value judgement could be formed on the efficacy of GPS in either time frame. The relative level of GPS effectiveness was determined first on a test-category-by-test-category basis and then as a composite for each generic range as a whole.

By contrast, the 20 year Life-Cycle Cost (LCC) analysis computed the differential life-cycle costs of three instrumentation options for each generic range: 1) GPS-based TSPI for both the near and far term, 2) non-GPS TSPI sources for both time periods, and 3) non-GPS-based TSPI in the near term but GPS in the far term. The latter, coupled with the effectiveness

analysis results, formed the basis for the GPS cost-effectiveness evaluation in the test and training range environment.

The generic ranges and the test categories they support are identified in Section 4.1 along with the pattern ranges on which each was based. The LCC approach and associated data base are presented in Section 4.2. Finally, the Measures-of-Merit (MOM) for the comparative effectiveness evaluation are presented in Section 4.3.

4.1 GENERIC RANGE SELECTION

Because of the disparity between test and training objectives, generic ranges were divided into two classes: those which could support the stringent Development Test and Evaluation (DT&E) accuracy requirements and those which are more suitable for training and large-scale inter-service exercises involving a large number of players but with somewhat relaxed accuracy requirements. Because Operational Test and Evaluation (OT&E) accuracy requirements are generally somewhere between those for DT&E and training, this test function was assigned to both range classes. A further breakdown of the generic ranges was performed based upon operational differences among the various weapon test categories, differences in the service-related training environments, and basic variations in existing DoD facilities.

As a result of the foregoing process, eight generic range types (along with their associated test and training categories), were chosen as shown below:

DT&E and OT&E

1. All-Altitude, Long-Range Weapons Range
   - Ballistic Missiles
   - ABM
   - ASAT

2. Low-Altitude, Extended-Range Weapons Range
   - Cruise Missiles
   - Penetration Bomber

3. All-Altitude, Short-Range Weapons Land Range
   - Aircraft
   - Drones
   - Missiles (A-A, A-S, S-A, S-S)
   - Land Vehicles

4. All-Altitude, Short-Range Weapons Water Range
   - Aircraft
   - Drones
   - Missiles (A-A, A-S, A-A)

Training and OT&E

5. Airborne Weapons Range
   - A-A Combat
   - A-S Weapon Delivery
   - Electronic Warfare
   - SAM Avoidance, Electronic Warfare
   - Operational Weapons Evaluation

6. Land-Based Weapons Range
   - Large Scale Land Exercises
   - Close Air Support
   - Joint Anti-Armor Operations
   - Operational Weapons Evaluation

7. Sea-Based Weapons, Fixed Baseline Range
   - A-S Weapon Delivery
   - Anti Ship Warfare
   - Electronic Warfare
   - Operational Weapon Evaluation

8. Sea-Based Weapons, Moving Baseline Range
   - Large Scale Exercises
   - Anti-Surface Ship Warfare
   - Anti-Air Warfare
   - Anti-Submarine Warfare
   - Operational Weapons Evaluation

The basic characteristics of each generic range -- TSPI equipment, land area, topography, etc. -- were selected by reference to pattern ranges, where a pattern range is a major DoD test or training range whose major test functions include (but are not necessarily limited to) those of the associated generic range, The primary pattern ranges were selected using the following groundrules:

- DT&E and OT&E generic ranges should have at least one primary pattern range from each service, if possible.
- OT&E and training ranges should be patterned along individual service lines.
- Every major range should be represented as a primary pattern for at least one generic range.

The resulting matrix at pattern ranges is presented in Table 4.1-1, with the range mnemonics expanded in Table 4.1-2.

4.2 LIFE-CYCLE COST APPROACH

4.2.1 Ground Rules

Computation of the Rough Order-of-Magnitude (ROM) life-cycle costs (LCC) for GPS- non-GPS-based systems at each generic range, was accomplished under the following ground rules:

> Differential Costs -- Each LCC analysis considered only the differential costs of GPS and non-GPS TSPI equipments at the generic range. Wherever equipments were common to both the GPS-based and non-GPS-based alternatives, the costs for those equipments were considered common to both and ignored. Only those equipments peculiar to one alternative and not the other were included in the calculations. As a result, each LCC analysis has implicit within it an unquantified common LCC base to which the differential LCC costs for each alternative are an addition.

> Constant Dollars -- Life-cycle costs were portrayed in constant FY 1982 dollars to avoid the confusing effects of the time value of money when comparing alternatives across differing time frames. Life-cycle cost comparisons are normally made in constant dollars due to the uncertainty of projecting inflation and discounting rates twenty years into the future.

> Learning Curve -- Average unit acquisition costs were calculated by applying a 92% slope unit learning curve.* The slope selected is based on GPS experience and is consistent with overall learning curve experience for DOD avionics equipments.

*A 92% slope unit learning curve implies an 8% reduction in unit cost for each doubling in production quantity.

TABLE 4.1-1
GENERIC PATTERN RANGE CANDIDATES

	TEST AND TRAINING RANGES																		
	ARMY						NAVY							AIR FORCE					
	WSMR	KMR	YPG	TCATA	CDEC	NTC	PMTC	PMRF	NATC	NWC	AFWTF	MSR	TRAINING	ESMC	WSMC	AFTFWC	AFFTC	UTTR	AD
Generic Ranges:																			
Training and OT&E																			
• Airborne Weapons	X		X				X	X		X	X					[X]	X	[X]	[X]
• Land-Based Weapons	X	X	X	[X]	[X]	[X]				X									
• Sea-Based Weapons (Fixed)							[X]	[X]			[X]		[X]*						
• Sea-Based Weapons (Moving)												[X]							
DT&E and OT&E																			
• All-Altitude, Long-Range Weapons	X	[X]		X			[X]	X		X	X			[X]	[X]				
• Low-Altitude, Extended Range Weapons	[X]	X					[X]	X	X	X	X				X	X	X	[X]	
• All-Altitude, Short-Range Weapons (Land)	[X]	X	[X]	X	X		X	X	X	[X]	X			X	X	X	[X]	X	[X]
• All-Altitude, Short-Range Weapons (Water)		X					[X]	X	[X]										[X]

[X] Primary Pattern Ranges

*Mainly VACAPES and FALLON

TABLE 4.1-2
TEST AND TRAINING RANGE CROSS REFERENCES

DESIGNATION	NAME	LOCATION	SERVICE
WSMR	White Sands Missile Range	White Sands, NM	Army
KMR	Kwajelein Missile Range	Marshall Islands, Pacific	Army
YPG	Yuma Proving Grounds	Yuma, AZ	Army
TCATA	TRADOC Combined Arms Test Activity	Fort Hood, TX	Army
CDEC	Combat Developments Experimentation Command	Fort Hunter Liggett, CA	Army
NTC	National Test Center	Fort Irwin, CA	Army
PMTC	Pacific Missile Test Center	Point Mager, CA	Navy
PMRF	Pacific Missile Range Facility	Barking Sands, Hawaii	Navy
NATC	Naval Air Test Center	Patuxent River, MD	Navy
NWC	Naval Weapons Center	China Lake, CA	Navy
AFWTF	Atlantic Fleet Weapons Training Facility	Roosevelt Roads, P.R.	Navy
VACAPES	Virginia Capes	Norfolk, VA Complex	Navy
FALLON	Fallon	Fallon Complex, NV	Navy
ESMC	Eastern Space and Missile Center	Patrick AFB, FL	Air Force
WSMC	Western Space and Missile Center	Vandenberg AFB, CA	Air Force
AFTFWC	Air Force Tactical Fighter Weapon Center	Nellis AFB, NV	Air Force
AFFTC	Air Force Flight Test Center	Edwards AFB, CA	Air Force
UTTR	Utah Test and Training Range	Hill AFB, UT	Air Force
AD	Armament Division	Eglin AFB, FL	Air Force

Costs were calculated for a twenty-year life-cycle with near-term defined as FY 1985-1987 and far-term as FY 1988-2004. Life-cycle costs included applicable development, acquisition, and operation and maintenance (O&M) costs for each alternative. In the calculation of average unit acquisition costs, the total quantity of each equipment type to be procured for all ranges was considered. The estimated number of tests and new test articles, plus the estimated number of training participants, was calculated across the twenty-year life-cycle for each generic range. The total number of equipments for all generic ranges was then used as the basis for calculating average unit acquisition costs. The unit costs used in the LCC calculations, therefore, reflect a consolidated buy of user equipments needed to support all the ranges. Similarly, the development cost for GPS-related equipment was prorated across the number of generic ranges requiring that equipment.

Three alternative scenarios were developed as a basis for the LCC analysis for each generic range: all-GPS, all non-GPS; and near-term non-GPS, far-term GPS. The all-GPS scenario includes the costs for development, acquisition and O&M of GPS equipements, with the commitment to GPS being made in the near term. The all non-GPS scenario includes only the costs for O&M of current non-GPS TSPI equipments retained, plus acquisition and O&M of new non-GPS TSPI equipments. The third scenario, in which the commitment to GPS is postponed until the far term, includes the costs for O&M of current non-GPS TSPI equipments until their replacement, plus development, acquisition and O&M of GPS equipments installed in the far term.

4.2.2 Unit Cost Development (GPS Equipment)

Two primary sources of information were employed during the generation of GPS equipment unit cost estimates: the

GPS JPO (and related staff support), and the prospective manufacturers of GPS equipment. Based upon conversations with both sources, estimates of first unit costs for each class of GPS equipment were developed. Total quantities of GPS equipments needed to support each generic range for its twenty-year life-cycle were then calculated and summed, as shown in Tables 4.2-1 and 4.2-2, in order to determine consolidated range requirements. Those quantities reflect best estimates (based on current range practices) of the number of tests, new test articles and participants in training exercises at variety generic ranges. Using those consolidated quantities, a 92% unit learning curve, and estimates for first unit costs, average unit acquisition costs were generated for both GPS user and ancillary range equipments shown in Tables 4.2-3 and 4.2-4, respectively.

In order to account for anticipated technology improvements in the GPS equipments and their impact on costs, the unit acquisition cost values for GPS equipment purchases deferred to the far term were reduced to 70% of the near-term values. This corresponds to an approximate 10% per year reduction over the three years separating the far-term buy from the near-term buy. For example, a GPS 5-channel receiver costing $40K in the near term is acquired for $28K in the far term due to anticipated, but undefined, technological improvements which can be expected to reduce unit cost. A 10% annual reduction factor is compatible with improvement factors used on similar high-technology items, e.g., JTIDS data terminals.

The corresponding annual O&M costs for each item of GPS user and ancillary range equipment shown in Tables 4.2-3 and 4.2-4 were again developed in consultation with the GPS JPO and prospective vendors and reflect annual O&M charges of

TABLE 4.2-1

BUY QUANTITIES - GPS (USER EQUIPMENT)

EQUIPMENT (NEAR-TERM/FAR-TERM)

GENERIC RANGE	POD WITH GPS	POD WITHOUT GPS	5 CHANNEL RECEIVER	1 CHANNEL RECEIVER		TRANSLATOR LOW POWER	TRANSLATOR HIGH POWER
				VEHICLE	MANPACK		
Airborne Training	90/90	0/90	0/69	---	---	(99-153)/(408-714)	---
Land-Based Training	30/60	---	0/69	360/3240	180/1980	(99-153)/(408-714)	---
Sea-Based Training (Fixed)	150/0	---	0/(200-370)	---	---	(285-480)/(1275-2210)	---
Long-Range Weapons	---	---	9/21	---	---	366/870	255/990
Extended-Range Weapons	---	---	6/G	---	---	135/540	---
Short-Range Weapons (Land)	20/0	---	0/(370-540)	---	---	(480-780)/(2210-3740)	---
Short-Range Weapons (Water)	12/0	---	0/(834-1446)	---	---	(666-1125)/2856-4845)	255/990
Total	302/150	0.90	15/(1563-2515)	360/3240	180/1980	(2130-3192)/8567-13633)	255/990

TABLE 4.2-2

BUY QUANTITIES - GPS RANGE EQUIPMENT

GENERIC RANGE	EQUIPMENT (NEAR-TERM/FAR-TERM)					REOCEIVER/ TIMING RECEIVER	SMILS SONOBUOYS
	GROUND-BASED PSEUDOLITES	AIRBORNE PSEUDOLITES	IRCC	DIFFERENTIAL RECEIVER	TRANSLATOR RECEIVER		
Airborne Training	21	-	3	3	36	3/3	-
Land-Based Training	75	-	9	3	3	3/3	-
Sea-Based Training (Fixed)	35	-	1	12	40	5/5	-
Long-Range Weapons	-	-	-	6	12	9/9	1800 (20 yr)
Extended-Range Weapons	36	-	9	18	3	3/3	-
Short-Range Weapons (Land)	35	-	5	15	36	5/5	-
Short-Range Weapons (Water)	27	9	3	9	24	3/3	-
Total	229	9	30	66	154	31/31	1800 (20 yr)

TABLE 4.2-3

GPS EQUIPMENT ACQUISITION AND O&M COSTS

ITEM	UNIT ACQUISITION COST (FY82$)	ANNUAL O&M COST (FY82$)	DEVELOPMENT COST (FY82$)
Full Capability (5-Channel) Receiver	$ 40K	$ 2K	$10M
Basic Capability (2-Channel) Receiver	$ 20K	$.5K	$10M
Translator (Long Range)	$ 40K	$ 1K	$ 2M
Translator (Short Range)	$ 10K	$.5K	$ 2M
Pod (with GPS)	$150K	$ 5K	$ 3M
Pod (without GPS, INS)	$ 90K	$ 3K	---

TABLE 4.2-4

ANCILLARY EQUIPMENT ACQUISITION AND O&M COSTS

ITEM	UNIT ACQUISITION COST (FY82$)	ANNUAL O&M COST (FY82$)	DEVELOPMENT COST (FY82$)
IRCC	$400K	$ 14K	---
Pseudolites	$250K	$ 10K	---
Ground Differential Station	$ 20K	$0.5K	$2M
Translator Receiver	$ 50K	$ 2K	$2M
Timing Receiver	$ 40K	$ 1K	---
Survey Receiver	$100K	$ 2K	---
Data Link/C^2 Net	$8.0-10.0M	$1.0-1.5M	---

between two and five percent of acquisition costs. This percentage range is consistent with typical O&M experience for similar equipments.

Any required development cost for each type of GPS user equipment was estimated by analogy to historical GPS development efforts and to programs of similar complexity. These selected ROM estimates, also shown in Tables 4.2-3 and 4.2-4, were checked with the prospective GPS equipment vendors for reasonability. Development cost for each type of GPS equipment was allocated to the individual generic ranges, based upon the quantity of each type of equipment procured for each range. Ranges not using a specific GPS equipment were not charged a share of its development cost.

With one exception, the ancillary equipment identified in Table 4.2-4 is either off-the-shelf or a development cost is specified (the ground differential and translator receivers are assumed to be modifications of the 1-2 channel and 5 channel receivers, respectively). New data link/command and control net systems specifically tailored to the GPS interface have not yet been specified in any level-of-detail and are not assumed in this analysis. As a conservative assumption, the cost analysis was predicated on GPS equipment interfacing with existing data link/C^2 nets, even if they have a non-GPS TSPI capability which would not be used. As an example, the data link/C^2 net cost indicated in Table 4.2-4 is the <u>full cost</u> of a 25 station multilateration system (see Section 4.2-3), even though the TSPI function of this system would not be used. If development and acquisition of a GPS-specific data link/C^2 net system proved cost effective, which is possible for a number of generic ranges, the cost of the GPS option would be reduced accordingly.

4.2.3 Unit Cost Development (Non-GPS Equipment)

The unit acquisition costs and annual O&M costs for non-GPS equipments, shown in Table 4.2-5, were based on combined TASC/BDM knowledge of and experience with DOD test and training ranges. Those unit costs are representative of recent range experience and reflect published range costs and current quotations to the maximum extent possible. For example, costs for tracking, laser and phased-array radars are consistent with figures published in Ref. 15. Similarly, air multilateration system (Ref. 16), and theodolite costs reflect recent vendor quotes. The ROM costs portrayed in Table 4.2-5 are considered accurate within an error band of ±25%.

4.3 EVALUATION BY MEASURES-OF-MERIT

The evaluation of potential GPS effectiveness for each generic range was predicated upon its performance capabilities relative to non-GPS options in the same time frame. Comparisons were made for each test category serviced by a generic range against a set of measures-of-merit (MOM) which were classed as "Drivers" (quantitative performance requirements) or "Considerations" (qualitative factors which were important but not hard requirements). Table 4.3-1 tabulates the MOM and summarizes comments pertinent to their evaluation.

In general, the "Drivers" corresponded to specific requirements extracted from the Tri-service Steering Committee requirements data base. Ratings were assigned as a "+" where GPS met the requirements and non-GPS alternatives did not, a "-" where the inverse was true, and a "0" where both options either met or failed the requirement. With "Considerations", however, ratings were specified based on GPS or non-GPS options

TABLE 4.2-5
NON-GPS EQUIPMENT ACQUISITION AND O&M COSTS

R-87441

TSPI SYSTEM	UNIT ACQUISITION COST ($FY82)	ANNUAL O&M COST ($FY82)
TARGET TRACKING RADAR	$ 3.0 M	$ 450 K
CINE THEODOLITE (DIGITIZED)	$ 750 K	$ 75 K
VIDEO THEODOLITE	$ 800 K	$ 90 K
LASER RADAR	$ 1.0 M	$ 40 K
LAND SYSTEM MULTI-LAT (CURRENT)	$ 8.0 M	$ 1.5 M
AIR SYSTEM MULTI-LAT (CURRENT)	$ 9.0 M	$ 1.0 M
LAND SYSTEM MULTI-LAT (IMPROVED)	$10.0 M	$ 1.5 M
AIR SYSTEM MULTI-LAT (IMPROVED)	$10.0 M	$ 1.5 M
PHASED ARRAY RADAR (3 FACED)	$40.0 M	$ 2.5 M
PHASED ARRAY (SINGLE FACE)	$ 6.0 M	$ 1.0 M

yielding significant operational advantages relative to each other. Where either a "+" or "-" was assigned, a specific justification was cited.

Following the examination of each MOM and an assessment of criticality for the application, a "GPS Applicability" rating was given for each test category. Extending this methodology over all test categories on the range yielded a composite generic range rating for each time frame.

Although the MOM evaluation yielded different results for each test range and test category due to the differing capabilities of the TSPI equipments available from test range to test range and varying vehicle characteristics, a common approach was used. For example, if a wide disparity in capabilities existed in favor of GPS but both options met the requirements, this factor would be reflected in a "0" under the appropriate "Driver" and a "+" under "growth potential" -- provided that the improvement could bring meaningful benefits in the testing of new weapon systems. In a second example, a "+" for the low altitude coverage MOM meant that vertical accuracy requirements could be met <u>at a specified altitude minimum</u>.

5. LONG-RANGE WEAPONS GENERIC RANGE ANALYSIS

The generic range used for All-Altitude, Long-Range Weapons covers a water area of 100 x 6000 nautical miles with terrain, in the form of coast line and islands, generally flat. The primary measurements occur either in the vicinity of the launch areas for all vehicles or the re-entry area for ballistic missiles. This generic range is patterned after the following DoD ranges: Eastern Space and Missile Center (ESMC). Western Space and Missile Center (WSMC), Pacific Missile Test Center (PMTC), and Kwajalein Missile Range (KMR). The range supports the DT&E and OT&E of ballistic missiles, anti-satellite missiles (ASAT) and anti-ballistic missiles (ABM). Although this range supports NASA space launches also, these were not analyzed since the requirement is for "best available" measurement capability only.

This chapter defines the TSPI requirements for these weapon systems and discusses the capability of GPS and non-GPS instrumentation to meet them. The latter includes special instrumentation; specifically, the Rawinsonde used for atmospheric velocity measurements, and SMILS, used for reentry body (RB) splash location measurements.

5.1 TSPI REQUIREMENTS ASSESSMENT

This section describes the TSPI measurement accuracies required for the vehicles to be tested. These requirements, tabulated in Table 5.1-1, are derived from the primary pattern range requirements provided in the Tri-Service data base.

TABLE 5.1-1
TSPI REQUIREMENTS*

Generic Range: All Altitude, Long-Range Weapons				
TEST PARAMETER	BALLISTIC MISSILES		ABM	ASAT
	BOOST	REENTRY		
• Real Time Accuracy (1σ)				
Position (x,y),(z) - ft	1000	1000	1000	1000
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	4	---	10	4
Timing (msec)	---	---	---	---
• Data Rate (#/sec)	10	10	10	10
• Post Test Accuracy (1σ)				
Position (x,y),(z) - ft	20	10	50	10
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.05	0.1-5	3	3
• Scoring Accuaricies (ft-1σ Circ)	N/A	50	---	†
• Number of Test Articles	1-4	10	1	1
• Coverage				
Altitude - kft	0-300	0-300	300	10-300
Distance - nm	500	400	230	150

*Parameter Ranges, where specified, reflect differing requirements for each test phase.

†Miss Scored by Onboard Instrumentation

Where requirements are unspecified or cover a broad range of values, corporate experience in weapons systems analysis is used to determine specific parameter values to be used in the range analysis.

Ballistic Missile - The real-time requirements for position and velocity measurements are nominally sufficient for range safety instantaneous impact prediction (IIP) calculations. The specific requirements depend in part on the missile

trajectory and its relationship to areas to be protected. The post-test velocity accuracy of 0.05 fps is needed to isolate guidance error contributors during the boost phase of flight.

For re-entry bodies, there is no firm requirement for real-time TSPI information since there is no range safety application. A 1000 ft position accuracy is used for the visual display of the test in progress. For post-test accuracies, the position requirement is tight to accommodate weapons systems analysis of maneuvering re-entry vehicles (MARVs). The velocity accuracy requirement is specified as a range of values since the depth of analysis performed on the inertially guided MARV is unknown.

ABM - The real-time accuracy for range safety purposes is critical for an ABM due to its high acceleration rates. Specific requirements are a function of the dynamic capabilities of the missile as well as the proximity of protected areas relative to the planned missile trajectory. The post-test requirement shown are consistent with any interceptor missile since their guidance laws are generally similar.

ASAT - The anti-satellite missile post-test accuracy requirement is similar to that required of other types of A-A and S-A interceptor missiles. The coverage region, however, is significantly greater and could in fact, extend beyond the range boundaries. A scoring device on board the missile or satellite is necessary to determine miss distance.

5.2 GENERIC NON-GPS RANGE BASELINES

This section describes the instrumentation used on the non-GPS test ranges. It also defines the instrumentation TSPI capabilities and relates them to the TSPI requirements.

5.2.1 Instrumented Range Description

The near- and far-term generic ranges are characterized by multiple tracking radars in both the launch and reentry areas (Figs. 5.2-1 and 5.2-2). Emphasis is placed on multiple sensor tracking since the accuracy of a multilateration ranging technique provides better accuracy than that associated with a single tracking radar with its inherently poor angle accuracy capability.

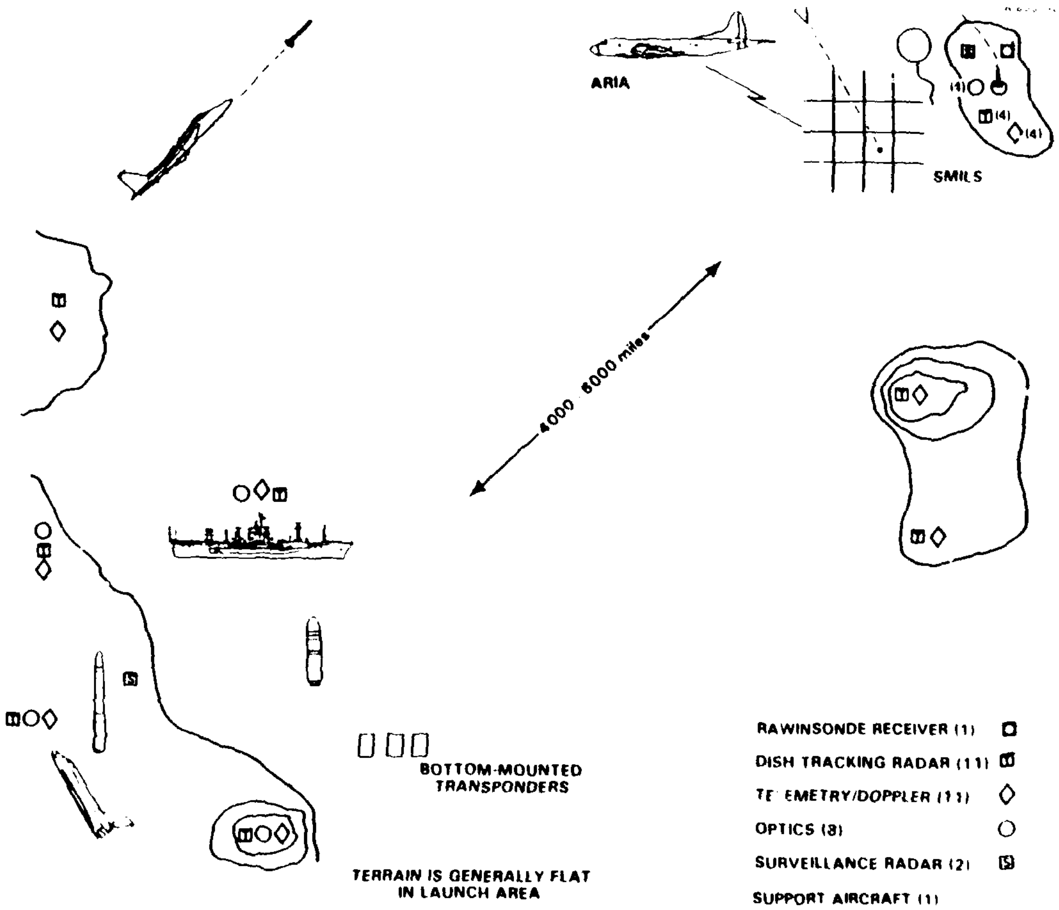

Figure 5.2-1 All-Altitude, Long-Range Weapons Generic Test Range: Near-Term Non-GPS Option

AD-A128 953 GPS (GLOBAL POSITIONING SYSTEM) RANGE APPLICATIONS STUDY(U) ANALYTIC SCIENCES CORP READING MA R G BALDWIN ET AL. 31 DEC 82 TASC-TR-4175-1

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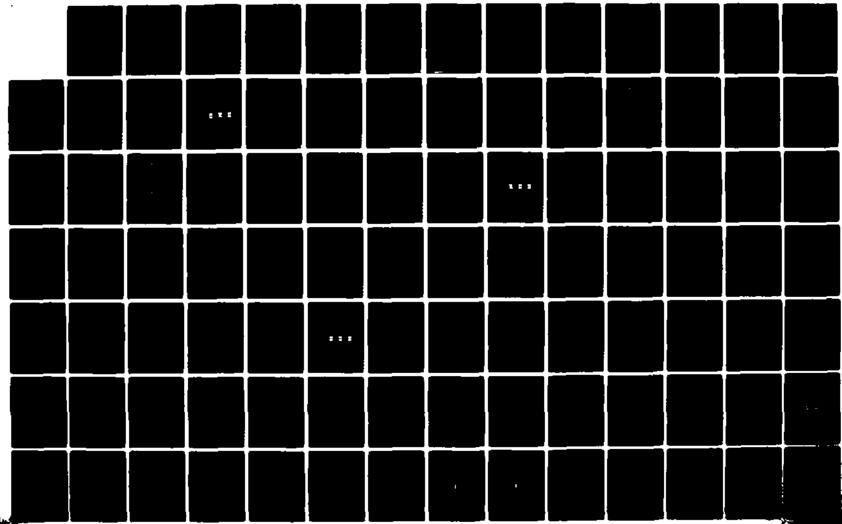
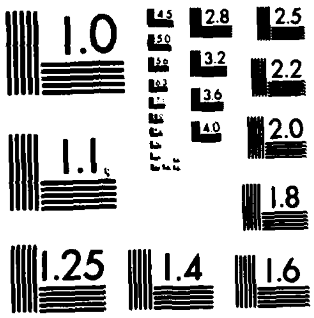
UNCLASSIFIED WSMC-TR-82-3 F04703-82-C-0220 F/G 17/7 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

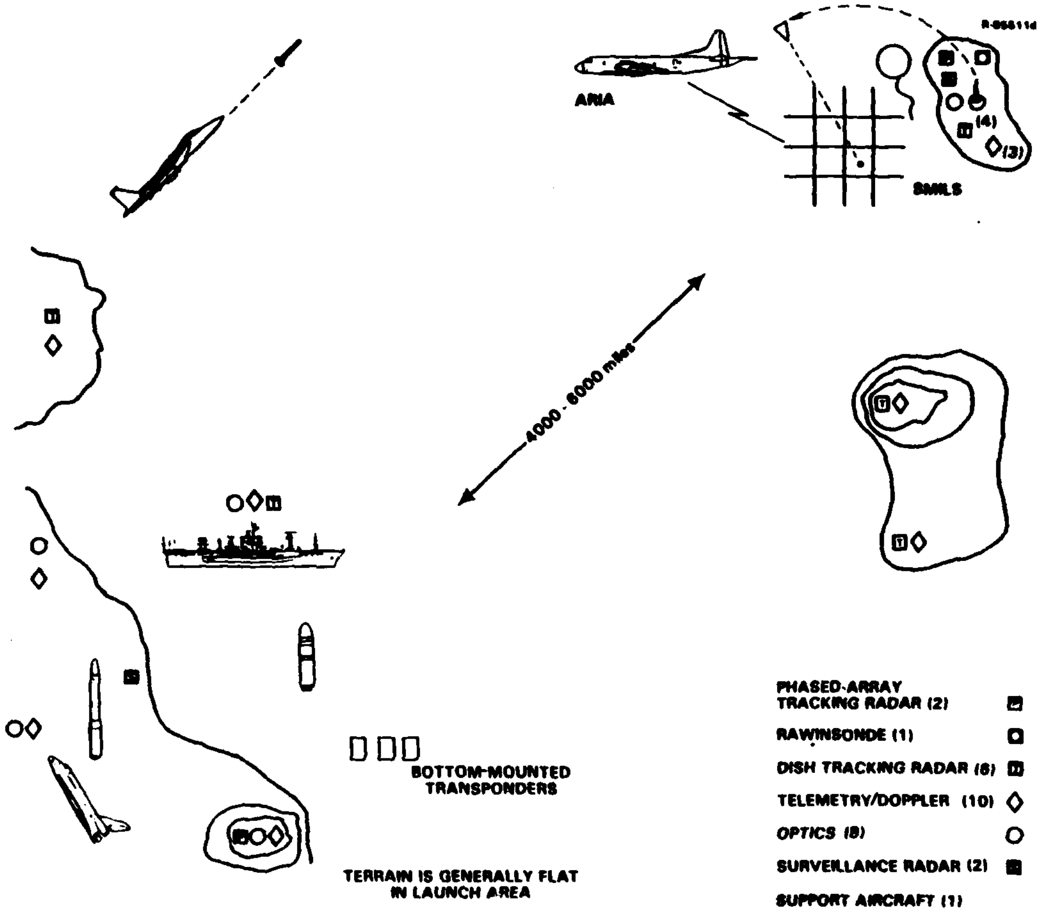


Figure 5.2-2 All-Altitude, Long-Range Weapons Generic Test Range: Far-Term Non-GPS Option

Besides the land-based tracking radars, the ranges require other resources to support ballistic missile testing. Telemetry stations are provided in the launch and reentry areas to collect vehicle performance data and measure vehicle velocity for sea-launched ballistic missiles while bottom-mounted transponders are used to measure the boat position and velocity states at launch. A launch area support ship is also provided for range safety purposes.

In the terminal area, a sonobuoy missile impact locating system (SMILS) is used to measure RB splash position.

This measurement is transmitted to an Advanced Range Instrumentation Aircraft (ARIA) on station in the area at the time of the test. A Rawinsonde, a device for measuring wind velocity and air density as a function of altitude, is also released in the terminal area. It provides needed information on the effects of the atmosphere on miss distance.

Near-Term Non-GPS Range - The major measurement instrumentation on the near-term non-GPS range consists of tracking radars and optics. The up-range radars are scattered about the launch area wherever feasible, to accommodate multilateration using the range-only measurements for more precise TSPI accuracies. The splash area also has several radars used cooperatively to derive a best estimate trajectory of RB, ABM and ASAT missiles. Optics systems are primarily used to further enhance RB measurement accuracies. Two surveillance radars are used for range safety to control unauthorized in the launch and reentry zones.

Far-Term Non-GPS Range - The far-term non-GPS range shows little change from the near-term range. Phased array multiple object tracking radars are used to replace some of the existing tracking radars, with one placed in the launch area, and another placed in the reentry area. Several dish tracking radars must be maintained because of the need to have physically separated radars to provide multilateration ranging measurements.

5.2.2 Non-GPS Range Capabilities

The TSPI capabilities of the previously described near- and far-term ranges are tabulated in Table 5.2-1. Included in the table are the required measurement accuracies as defined in Section 5.1. The near-term and far-term capabilities are

TABLE 5.2-1

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All Altitude, Long-Range Weapons (DT&E, OT&E)								
TEST PARAMETER	BALLISTIC MISSILES (BOOST)		BALLSTIC MISSILES (REENTRY)		ABM		ASAT	
	REQUIREMENTS	CAPABILITIES	REQUIREMENTS	CAPABILTIES	REQUIREMENTS	CAPABILITIES	REQUIREMENTS	CAPABILITIES
• Real-Time Accuracy (1σ)								
Position (x,y),(z) - ft	1000	200	1000	300	1000	300	1000	200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	4	20	---	30,35	10	30	4	10
Timing (msec)	---	---	---	---	---	---	---	---
• Data Rate (#/sec)	10	10	10	10	10	10	10	10
• Post-Test Accuracy (1σ)								
Position (x,y),(z) - ft	20	20	10	10	50	10	10	50
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.05	0.05	0.1-5	0.2	3	0.2	3	3
• Scoring Accuracy (ft-1σ Circ)	---	---	50	50	---	---	†	†
• Number of Test Articles	1-4	1-4	10	1	1	1	1	1
• Coverage								
Altitude - kft	0-300	10-300	0-300	20-300	300	300	10-300	10-300
Distance - nm	500	500	400	400	230	230	150	150

*Parameter ranges, where specified, reflect differing requirement for each test phase.

†Miss scored by onboard instrumentation.

identical since the far-term range upgrade provides no improved measurement capability.

Ballistic Missiles (Boost) - Table 5.2-1 shows that the real time velocity capability of the non-GPS range does not meet the requirement. The significance of this difference depends on how tightly the allowable trajectory deviation needs to be controlled. The post-test accuracy capability, however, is sufficient to meet the requirements under good measurement geometry conditions. The capability shown is based on using several tracking radars strategically placed as a ranging multilateration system. As a result of the need for multiple measurement resources for each target, the number of targets from which accurate TSPI information can be obtained is limited by the number of radars available.

Since tracking radars are used for a majority of TSPI measurements, the minimum altitude target that can be observed is a function of minimum elevation angle (three degrees for a one degree tracking beam) and range from the radar to the vehicle. As an example, SLBM launches can occur as much as fifty miles from the tracking radars, resulting in a minimum altitude of 15,000 feet at which measurements can be made. This minimum altitude constraint only applies to SLBM launches, since the ABM and ground-based ballistic missiles are launched much closer to the tracking radars.

Ballistic Missiles (Reentry) - Table 5.2-1 shows that the altitude requirement is not met by non-GPS instrumentation in the reentry area as a result of the same radar tracking limitations described earlier. The table also shows that the post-test velocity accuracy needed for maneuvering RB's is not matched by the range capability.

ABM and ASAT - The requirements vs capability table shows that the only capability deficiency of this non-GPS range for ABM and ASAT vehicles is related to real-time velocity accuracy. Again (as in the case of the ballistic missile), the significance of this deficiency is a function of the missile trajectory and the relationship to areas to be protected.

In summary, it is clear that the non-GPS range instrumentation meets the range requirements with the exception of altitude coverage and velocity accuracy. Good TSPI is not available at low altitudes which imposes a significant burden on ballistic missile boost phase analysis.

5.3 GPS SCENARIO DEVELOPMENT

In this section, the GPS baseline range is described in the same manner as that used in Section 5.2 for the non-GPS range. However, two additional aspects are covered -- a comparison of GPS vs non-GPS range resources, and the issues associated with implementing a GPS-based range.

5.3.1 Instrumented GPS Range Description

Figure 5.3-1 shows the GPS instrumentation used for obtaining TSPI measurements in both the near and far term. The near-term availability requirements are met in general even without pseudo-satellites because tests, which are performed relatively infrequently, can be scheduled to occur during the two hour daily coverage window of the Phase II installation. However, coverage can be significantly less (in the near term) for ballistic missile tests where the window must cover both the launch and terminal areas during the same test.

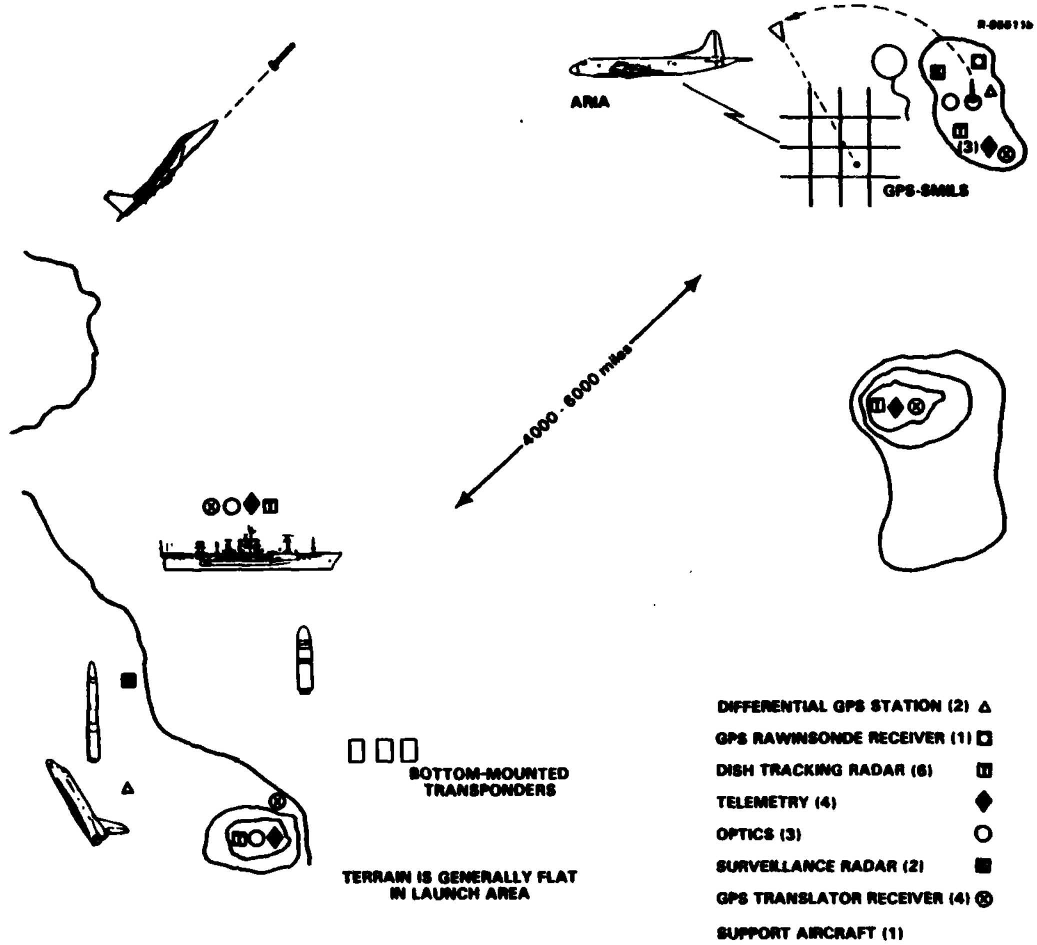


Figure 5.3-1 All-Altitude, Long-Range Weapons Generic Test Range: Near/Far-Term GPS Option

Translator signal receivers were placed throughout the launch and reentry areas of the range to obtain real-time tracking information for range safety and for quick-look analysis purposes. These receivers require line-of-sight to the translator-equipped test vehicles in order to obtain TSPI data. A second GPS resource is the portable GPS SMILS, which replaces the fixed SMILS net used on the non-GPS range. Its relative advantage lies in the fact that GPS SMILS is self-surveying. The function of the differential GPS stations shown in the

figures in both the launch and reentry areas is to support the precision post-mission measurement accuracies required for ballistic missile test analysis. Finally, a Rawinsonde fitted with a GPS translator can provide accurate velocity measurements of prevailing winds in the reentry areas.

Table 5.3-1 provides a list of GPS and non-GPS instrumentation resources to support both the near- and far-term ranges. The GPS instrumentation are the same for both time frames while differences exist between non-GPS alternatives. Comparing the non-GPS near-term and far-term ranges shows that the major change between them is a significant reduction of dish tracking radars in the far term in favor of phased array, multiple object tracking radars. Some of the dish tracking radars must be maintained because the quoted TSPI accuracy capability is based on using the radars as a ranging multilateration system. A second reason they are not eliminated (for GPS or non-GPS) is because some are still required for special measurements such as reentry vehicle signature characteristics testing.

One difference between the GPS and non-GPS ranges is the elimination of the telemetry/doppler stations which are replaced by telemetry stations since, with GPS, a direct measurement of doppler is obtained. Another difference is the replacement of existing instrumentation equipment with GPS SMILS and a GPS Rawinsonde. Finally, the differential GPS stations and GPS translator signal receivers are new equipments unique to the GPS range.

5.3.2 GPS Range Capabilities

The GPS range TSPI measurement capability is a function of the GPS instrumentation configuration used by each vehicle.

TABLE 5.3-1
ALL-ALTITUDE, LONG-RANGE WEAPONS

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Telemetry/Doppler	---	11	GPS Equipment		
TLM/C^2 Data Link	4	11	Differential Station	2	---
Tracking Radar			Geoceiver	3	---
Dish	6	11	Timing Receiver	3	---
Optics	3	8	Translator Receiver	4	---
BMT Array	1	1	Surveillance Radar	2	2
SMILS	1*	1	Test Article Equipment	YES	YES
RAWINSONDE Receiver	1*	1	Support Aircraft	1	1
			Support Ship	1-2	1-2

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Telemetry/Doppler	---	11	GPS Equipment		
TLM/C^2 Data Link	4	11	Differential Station	2	---
Tracking Radar			Geoceiver	3	---
Dish	6	6	Timing Receiver	3	---
Phased Array	---	2	Translator Receiver	4	---
Optics	3	8	Surveillance Radar	2	2
BMT Array	1	1	Test Article Equipment	YES	YES
SMILS	1*	1	Support Aircraft	1	1
RAWINSONDE Receiver	1*	1	Support Ship	1-2	1-2

*GPS translators supply TSPI for application.

The capabilities versus requirements are shown in Tables 5.3-2, 5.3-3, 5.3-4, and 5.3-5. The GPS measurement equipment block diagrams shown in Figs. 3.4-1 through 3.4-4 apply.

Ballistic Missile - The ballistic missile measurement capability for both boost and reentry (Tables 5.3-2 and 5.3-3) are met through the use of an onboard translator in conjunction with a differential GPS station in the measurement areas

TABLE 5.3-2
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Long-Range Weapons (DT&E, OT&E)

Generic Test Category: Ballistic Missiles (Boost)

TSPI Configuration Number: 3. (Onboard Equipment Section C/A-Code Translator - Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	1000	25,41	25,41
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	4	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	20	6,10	6,10
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	0.05	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	1-4	4	4
• Coverage			
Altitude - kft	0-300	0-300	0-300
Distance - nm	500	500	500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

of interest. Figure 3.4-3 shows the equipment configuration. The translator can be mounted in the equipment section for boost measurements or within the RB for boost and reentry measurements.

The IMU is desired for both boost and reentry measurements to provide aiding information to the ground receiver since the receiver must "coast" during those periods when no

TABLE 5.3-3
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Long-Range Weapons (DT&E, OT&E)

Generic Test Category: Ballistic Missiles (Reentry)

TSPI Configuration Number: 3. (Onboard Reentry Vehicle C/A-Code Translator - Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	1000	25,41	25,41
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	--	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10	6,10	6,10
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-5	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	50	50	50
• Number of Test Articles	10	10	10
• Coverage			
Altitude - kft	0-300	0-300	0-300
Distance - nm	400	400	400

*Parameter ranges, where specified, reflect differing requirements for each test phase.

downlink transmission signals are available due to plume or plasma effects. For post-processing of reentry data, it is also desirable to collect IMU data so that this information can be used to bridge the gap of lost GPS measurements.

ABM - The anti-ballistic missile TSPI measurement capability (Table 5.3-4) meets the requirements easily with

TABLE 5.3-4

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Long-Range Weapons (DT&E, OT&E)

Generic Test Category: Anti-Ballistic Missiles (ABM)

TSPI Configuration Number: 1. (Onboard C/A-Code Translator GPS Translator Receiver (IMU Aided)) 3. (Onboard C/A-Code Receiver)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	1000	30,51	30,51
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	50	18,30	18,30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	3	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	1	1	1
• Coverage			
Altitude - kft	0-300	0-300	0-300
Distance - nm	230	230	230

*Parameter ranges, where specified, reflect differing requirements for each test phase.

either an onboard translator or receiver. Figure 3.4-3 shows the translator configuration that would be used to support missile tests. The differential mode need not be used since the measurement accuracy requirements preclude its use. IMU data supplied by the ABM must be sent to the ground receiver where it will provide the required "aiding" information for

TABLE 5.3-5
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Long-Range Weapons (DT&E, OT&E)

Generic Test Category: Anti-Satellite Missiles (ASAT)

TSPI Configuration Number: 1. (Onboard C/A-Code Translator)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real Time Accuracy (1σ)			
Position (x,y),(z) - ft	1000	30,51	30,51
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	4	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10	18,30	18,30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	3	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	†	--	--
• Number of Test Articles	1	1	1
• Coverage			
Altitude - kft	10-300	10-300	10-300
Distance - nm	150	150	150

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Miss scored by onboard equipment.

proper code and carrier tracking. The choice of a high- or low-power translator would be predicated on whether the intercept is to take place at high or low altitudes.

The translator is prescribed in this section because it is less costly than the receiver option. However, there is some risk associated with supplying IMU data to a ground-based

receiver to provide real-time track loop aiding in high acceleration environments. If the translator configuration is not successful, a GPS measurement solution can still be obtained using an onboard GPS receiver, directly aided by the ABM IMU (Fig. 3.4-1).

Anti-satellite Missile - The anti-satellite missile TSPI measurement requirement can be met through the use of an onboard high-power translator operating in the non-differential mode (see Tables 5.3-5). It is anticipated that volume constraints would preclude the use of a receiver in the ASAT.

5.3.3 GPS Application Issues

To successfully develop a GPS instrumentation system for use on the All-Altitude Long Range Weapon Range, several issues must be addressed. These issues relate to technical risks associated with development of a GPS-configured instrumentation system.

Antenna Development - A significant risk may be associated with the GPS antenna development in conjunction with strategic missile testing. The primary problem is building a missile equipment section- or RB-mounted antenna that maintains a uniform phase and gain characteristic independent of platform aspect angle. For the ASAT, there is some risk due to the available surface area of the miniature vehicle.

Packaging - The packaging issue relates to the available volume in which a complement of instrumentation can be placed on a vehicle. The anti-satellite missile is the only vehicle where packaging is perceived to be a problem, even with translators. Although it's questionable whether an IMU, let alone a receiver, could fit on the homing vehicle, access to the the onboard IMU can aid tracking through the boost phase.

Telemetry Bandwidth - Telemetry bandwidth becomes a concern only for vehicles carrying translators. If ten RB's are instrumented for a ballistic missile test, the signal spectrum requirement approaches 30 MHz, which may be greater than the allotted bandwidth available to range users. In most testing scenarios, a maximum of three RB's would be instrumented and would not result in saturating telemetry bandwidth capability.

GPS Receiver Initialization - Range safety requires real-time TSPI information from a vehicle under test. Therefore an onboard or ground-based translator signal receiver could acquire and track the satellites prior to missile launch if provision is made for an exterior antenna for vehicles in silos. For submarine launched missiles, however, the translator receiver cannot acquire translated satellite signals until after missile broach. Therefore the receiver must lock up quickly to provide trajectory information for range safety. To ensure this quick signal acquisition, a priori missile launch conditions must be supplied to the receiver during the first few seconds after broach.

The anti-satellite missile has a similar problem, albeit not as critical. In this case, the receiver acquisition of the translated satellite signal must be supported by missile TSPI information to ensure quick lock-up. Therefore, real-time launch aircraft TSPI information must be provided to the translator receiver during its acquisition attempt.

GPS Receiver Tracking - For the ABM, satellite signal acquisition is not a problem. Its launch point is well known and acquisition can occur prior to launch. However, because of the missile's high acceleration capability, there is some risk in the ground receiver not being capable of maintaining track on the translated satellite signals. The risk can be

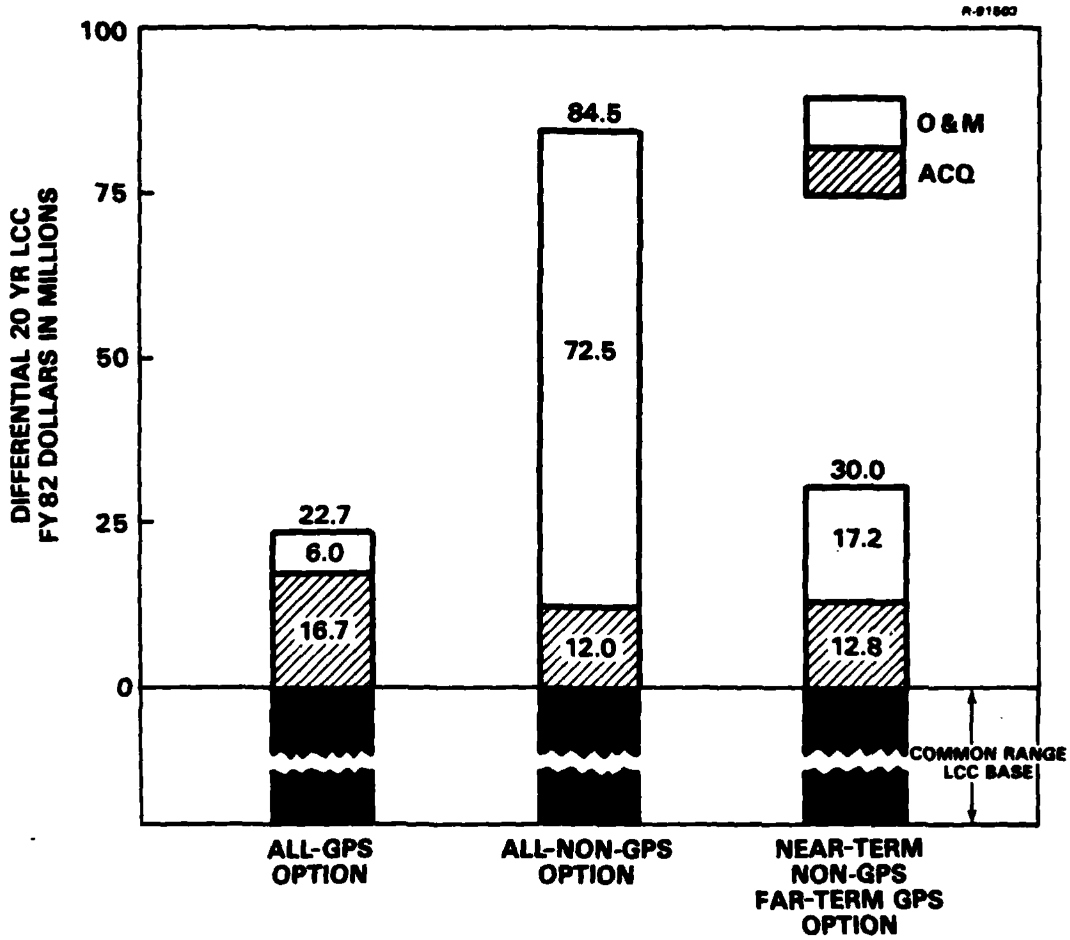
minimized by 1) supplying IMU aiding data to the receiver, 2) ensuring that the receiver has sufficient bandwidth to accommodate the aiding information.

ECM degradation - The ABM will be tested in an ECM environment. Care must be taken to ensure that the telemetry link is not compromised resulting in a degraded range safety capability. Similarly, plume- and plasma-related effects are a concern for missile boost and RB reentry, respectively.

5.4 LIFE-CYCLE COST COMPARISON

The results of the Long-Range Weapons generic range differential 20-year life-cycle cost comparison is shown in Fig. 5.4-1. The cost elements presented in Section 4.2, coupled with the equipment buys summarized in Tables 5.3-1 and 4.2-1 formed the basis for this estimate. The major contributors to cost in the all-GPS option are the development, acquisition and O&M of GPS range equipments and long-range translators for the test articles. Also included in the all-GPS option costs (and peculiar to this generic range) is a $1M development cost for a dish antenna for the real-time, high power GPS translator receiver. For the purposes of this analysis, the GPS SMILS sonobuoys are considered part of the basic GPS or non-GPS range capability and have, therefore, not been costed.

The all-non-GPS option costs are driven by the O&M of dish radars and telemetry/doppler systems in the near term and by the acquisition and O&M of two single-faced, phased array radars in the far term. The costs for the mixed option reflect lower acquisition costs, because GPS equipments are not procured until the far term, and higher O&M costs, because the non-GPS dish radars are maintained through the near term.



- Real-Time Long Range GPS Translator Receiver
- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based on Consolidated Buy

Figure 5.4-1 All-Altitude, Long-Range Weapons Range LCC Comparision

The cost advantage for the two GPS options over the all-non-GPS option is significant, as shown in Fig. 5.4-1. Even varying the unit costs of non-GPS equipments downward by 25%* (to reflect the downside error of ±25% accuracy, as stated

*Costs were reduced by 25% on the phase array radars, telemetry/ doppler systems, and dish radar acquisition and/or O&M costs.

in Chapter 4) and increasing the cost of GPS translators by 25% does not close that gap. Under all foreseeable circumstances, therefore, the GPS options should be significantly less expensive than the all-non-GPS option. Furthermore, from a cost aspect, it appears that the commitment to GPS should be made for this range in the near term to avoid the additional O&M of dish radars, which drive the mixed option costs over the all-GPS option costs.

5.5 GPS RANGE EFFECTIVENESS EVALUATION

The effectiveness of the near- and far-term GPS ranges relative to the comparable non-GPS options is shown in Table 5.5-1. This table is a composite of the effectiveness assessment for each vehicle. The real-time velocity requirement can only be met by GPS for any of the vehicles being tested although the significance of this deficiency is a function of how tight the flight trajectory must be controlled for range safety purposes. In addition, GPS offers the only option for which the post-test velocity accuracy and low altitude coverage requirements are met for ballistic missiles. A precise post-test velocity capability is needed to isolate guidance error contributors associated with inertial systems while the capability for low altitude coverage provides a means to isolating guidance error mechanisms in submarine launched missiles where measurements very early in the boost phase of flight are important.

There are both risks and benefits associated with ABM and ASAT applications of GPS. The risks are associated with translator size (ASAT) and the ability to tolerate the high dynamic environment (ABM), although the latter problem is offset by the cost of the near-term dish radars for the non-GPS system.

TABLE 5.5-1

GPS COMPOSITE EFFECTIVENESS SCREENING
(ALL-ALTITUDE, LONG-RANGE)

Generic Range: All-Altitude, Long-Range Weapons (DT&E, OT&E)
Test Category: Ballistic Missile, ABM, Anti-satellite Missile

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
DRIVERS:				
• Real-Time Accuracy	+	+	All	Velocity Measurement Needed for IIP
• Post-Test Accuracy	⊞	⊞	Ballistic Missile	Better Weapon System Analysis
• Broad Coverage	0	0		
• Low Altitude Coverage	⊞	⊞	Ballistic Missile	
• Number of Players	0	0		
• Data Rate	0	0		
CONSIDERATIONS:				
• Integration	0	0		
• Technical Risk	+, -	-	(-) ASAT Packaging (+) ABM Angle Track Acceleration Capability Increased. Accuracy Improves Missile Trajectory Analysis	
• Growth Potential	+	+		
• Standardization	+	+		
• Portability	+	+	All; Improved Due to Fewer Resources	
• Availabilty	-	+	All; (-) Small Satellite Window, (+) Better MTBF	
• Data Timeliness	0	0		
GPS APPLICABILITY	HIGH	HIGH	Significant Motivation for GPS Option	

*GPS vs non-GPS Options

Rating Key:
GPS Better +
GPS Same 0
GPS Worse -
Critical □

Another potential benefit of GPS lies in the area of growth potential due to the precise velocity available with GPS. This is an important factor for ballistic missiles where better velocity measurement accuracy results in better isolation of error contributors in the inertial guidance system. Finally, standardization, portability and availability are generally enhanced with the GPS range because it uses fewer resources than the non-GPS range. However, near-term availability shortcomings of GPS may be a disadvantage since the satellite window is less than two hours a day.

Overall, Table 5.5-1 shows that a GPS instrumented range is essential to provide the measurement quality necessary for ballistic missile weapon system analysis. For ABM and anti-satellite missile testing, benefits lie in the area of range safety and operations.

6. EXTENDED-RANGE WEAPONS GENERIC RANGE ANALYSIS

The generic range used for extended-range weapons testing covers an area of 100 x 600 nm. It is patterned (primarily) after three existing ranges: Pacific Missile Test Center (PMTC), White Sands Missile Range (WSMR), and Utah Test and Training Range (UTTR). The generic range is used for testing cruise missiles and low altitude penetration bombers.

6.1 TSPI REQUIREMENTS ASSESSMENT

The TSPI requirements are shown in Table 6.1-1. They are based on stated pattern range requirements where available; however, corporate experience in weapon system analysis was used to provide unspecified or loosely specified parameter values in several key areas. The rationale for these selections is provided below.

Real-Time Accuracy - The real-time accuracy requirement is specified for range safety purposes, i.e., position and velocity information is needed to determine the instantaneous impact point (IIP). A real-time position accuracy requirement of 5-30 ft was stated in the requirements data base provided by one of the pattern ranges, along with the 10 fps velocity requirement shown in Table 6.1-1. On inspection, the stringent position requirement was based on a desire to difference tracking radar returns to derive the velocity estimate. The real-time position and velocity accuracies stated in Table 6.1-1 are sufficient to meet IIP requirements, independent of the manner in which the data is obtained.

TABLE 6.1-1

TSPI REQUIREMENTS

Generic Range: Low-Altitude, Extended-Range Weapons Generic Test Category: Cruise Missile, Bomber

TEST PARAMETER	TSPI REQUIREMENT
• Real-Time Accuracy** (1σ)	
Position (x,y),(z) - ft	> 100
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10
Timing (msec)	--
• Data Rate (#/sec)	20
• Post-Test Accuracy (1σ)	
Position (x,y),(z) - ft	10
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	0.1
• Scoring Accuracy (ft-1σ Circ)	1
• Number of Test Articles	1
• Coverage	
Altitude - kft	0.1 - 30
Distance - nm	100 x 600

**Cruise missile only.

Post-Test Accuracy - The pattern ranges specified a post-test velocity accuracy requirement of 5 fps, which is too coarse for weapon system analysis. A cruise missile will fly long segments of its trajectory using inertial guidance data. Velocity errors in the inertial system are a major contribution to the position uncertainty computed by the navigation computer. As a result, the missile velocity measurement accuracy obtained by the range should be a fraction of the possible velocity

errors seen by the navigation system. The 0.1 fps measurement accuracy is the maximum value required to perform guidance system analysis. Better velocity accuracy (0.01 - 0.02 fps), although not required, is desired. This improved accuracy measurement capability will allow isolation of specific contributors to the inertial system errors.

The scoring accuracy requirement is associated with impact scoring for hard structure munutions (HSM) non-nuclear applications. Obviously scoring requirements for nuclear applications would be less stringent.

6.2 GENERIC NON-GPS RANGE BASELINES

This section describes the instrumentation selected for the non-GPS test range options. It also defines the instrumentation TSPI capabilities and relates them to the TSPI requirements.

6.2.1 Instrumented Range Description

Two non-GPS ranges are described. One range portrays a complement of TSPI instrumentation that is representative of the near-term equipment used by the pattern ranges. The second range portrays a complement of equipment representative of the planned pattern range far-term upgrades.

Figures 6.2-1 and 6.2-2 show the layout and topography of the near- and far-term generic ranges for extended range weapons. The figures also show a cruise missile launch over the ocean. This missile is inertially guided over the mountainous terrain to each of four way points. These way points are generally situated at terrain locations which have unique

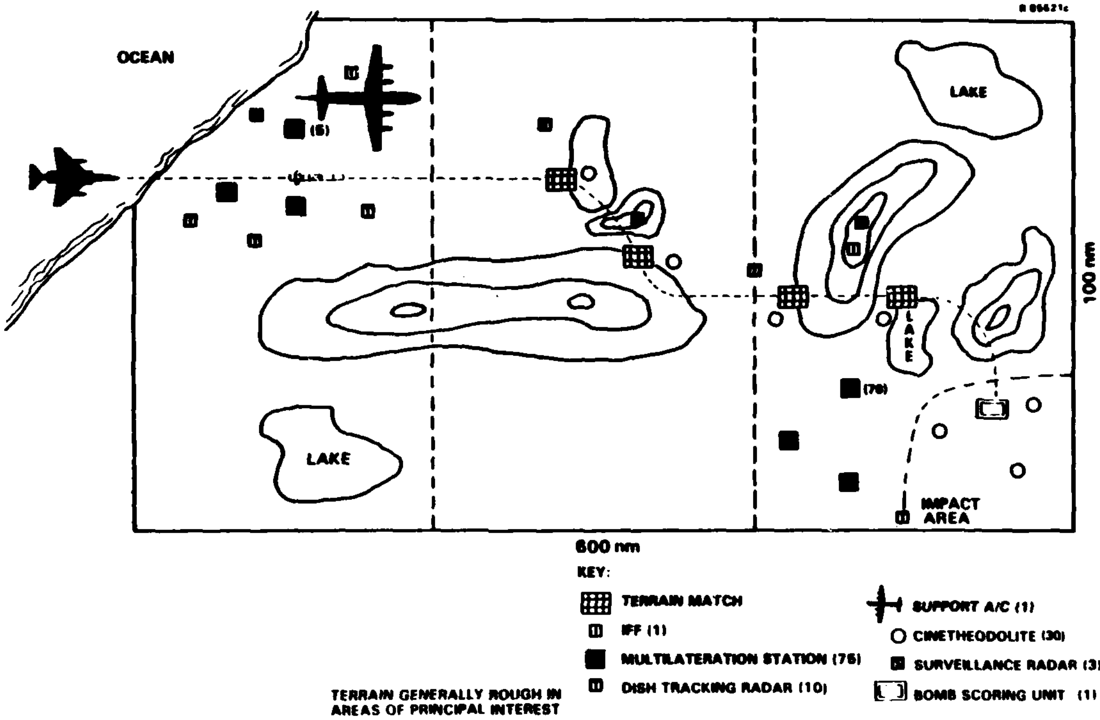


Figure 6.2-1 Low-Altitude, Extended-Range Weapons Generic Test Range: Near-Term Non-GPS Option

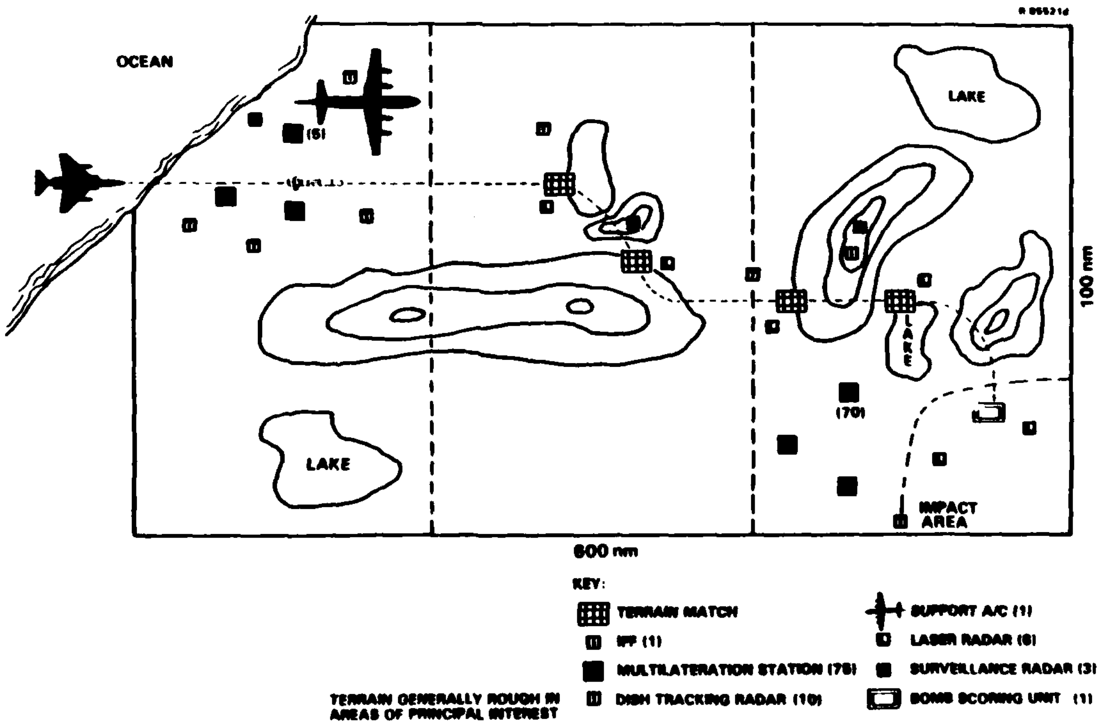


Figure 6.2-2 Low-Altitude, Extended-Range Weapons Generic Test Range: Far-Term Non-GPS Option

topographic characteristics. At these points, terrain mapping occurs and the information is used to provide position updates to the guidance system. At the terminal portion of the range, there is an impact area where the missile can be retrieved or munitions dispersed. This scenario range is also used for penetration bombers which fly at very low altitudes above the mountainous terrain to drop munitions in the scoring area.

The instrumentation is configured to support three segments of a test flight. The launch area is fairly large and is instrumented by a land-based multilateration system which covers launches over land. For launches over the ocean, the multilateration system provides poor GDOP therefore, tracking radars are used. Because of line-of-sight and multipath limitations, the minimum launch altitude capabilities are restricted to a height consistent with a minimum 3-5 degree elevation angle at the radar site.

The mid area of the test range has little instrumentation available. Tracking radars are scattered through the area, and provide position information whenever the vehicle is in sight. Additional instrumentation is clustered around those areas where way point updates to the navigation or guidance system will occur.

The terminal area of the range is heavily instrumented. TSPI data is required for both scoring activities and terminal guidance system analysis. A multilateration system is used to cover a wide area of terrain over which the missile is to maneuver. Optics systems are also used in local areas to both support the guidance system analysis and also to provide scoring information. A bomb scoring unit is included specifically to score munitions.

The range also has surveillance radars and an IFF system. These instruments provide information on non-test vehicles within the range and are used to support the range safety function of detecting unauthorized aircraft within the controlled air space.

Near-Term Non-GPS Range - There are five multilateration stations defined for the launch area. A small number of stations is needed because they are placed on high ground and are used to cover an area toward the sea where the terrain is relatively flat. This multilateration system does not provide continuous coverage in the opposite direction because of hilly terrain.

Tracking radars are used to provide coverage in the hilly terrain area. The radars also provide measurements at long ranges over the water. A total of ten dish tracking radars was selected to cover this range. The spacing of the radars is 80 miles apart, which results in a triangulated position measurement accuracy of 20 ft/axis. For test vehicles at an altitude of 10,000 ft, continuous coverage is obtained. The amount of coverage decreases linearly as the vehicle operating altitude is reduced.

Cinetheodolites are used at each of four way points and in the scoring area. A total of 6 instruments is generally desirable for each area. This number is based on the number of independent measurement stations needed, the expected equipment reliability during the test, and manual tracking difficulty that the operator may have. This number is consistent with the resources allotted to tracking at WSMR.

A seventy station multilateration system is used to provide coverage over 750 square miles in the terminal area.

The number of stations shown assumes a one degree elevation mask angle at each station, 25 ft high towers, and a minimum vehicle altitude of 500 feet. The number of stations is also consistent with the expected number of stations needed at UTTR.

Far-Term Non-GPS Range - The far-term non-GPS range uses the same complement of instrumentation as shown for the near-term range, with one exception, i.e., the cinetheodolites are replaced with laser trackers which are more reliable and provide position data without the need for multilateration. One tracker is positioned at each way point and two are placed in the terminal area for scoring purposes.

6.2.2 Non-GPS Range Capabilitities

The TSPI capabilities of the previously described near- and far-term ranges are given in Table 6.2-1. The TSPI requirements described in Section 6.1 are included in the table for comparison purposes. Since the capabilities for near- and far-term ranges are identical, the comparison of capabilities and requirements is made without reference to time frame.

The real-time accuracy capability is based on tracking radar and multilateration systems capabilities. For both types of measurements systems, the position accuracy can be met. However, the velocity is derived rather than measured and does not meet the accuracy requirements, particularly at low altitudes where measurement geometry is poor.

Post-test position accuracy is roughly 20 ft using tracking radars or multilateration systems, which does not meet the required position accuracy. At locations with limited area coverage needs, optics systems can be used to provide the required accuracy. The post-test velocity accuracy is significantly poorer than the requirement. The value shown is based

TABLE 6.2-1

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Low-Altitude, Extended-Range Weapons
Generic Test Category: Cruise Missile, Bomber

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy** (1σ)			
Position (x,y),(z) - ft	>100	100	100
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	10	15-100	15-100
Timing (msec)	--	--	--
• Data Rate (#/sec)	20	20	20
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10	20 (3††)	20 (3††)
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1	1††	1††
• Scoring Accuracy (ft-1σ Circ)	1	§	§
• Number of Test Articles	1	1	[illegible]
• Coverage			
Altitude - kft	0.1 - 30	0.5 - 30	0.5 - 30
Distance - nm	100 x 600	100 x 600†	100 x 600†

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Cruise missile only.

†Continuous coverage only in launch and terminal areas.

††Waypoint measurements via optics down to 100 ft altitude.

§Requires dedicated impact scoring system

on derived velocity measurements from optically-measured position data. Wide area coverage provided by radars or multilateration systems results in derived velocity values greater than 10 fps.

The altitude coverage is dependent on terrain and the measurement system used. In general, wide area coverage cannot reasonably be obtained below an altitude of five hundred feet. Limited coverage at way points can generally be obtained down to an altitude of 100 feet or less, using optics-based systems.

In summary, it is shown that existing non-GPS measurement resources are not sufficient to provide the required coverage or velocity accuracy over the test range areas.

6.3 GPS SCENARIO DEVELOPMENT

In this section, GPS baseline ranges are described in the same manner as that used in Section 6.2 for the non-GPS ranges. Two additional aspects are also covered: comparison of GPS vs non-GPS range resources, and the issues associated with implementing a GPS-based range.

6.3.1 Instrumented GPS Range Description

A near-term and far-term generic range using GPS instrumentation for obtaining TSPI measurements are shown in Figs. 6.3-1 and 6.3-2, respectively. All of the features of the range, already described in Section 6.2, are still applicable. Only the instrumentation resources have changed.

Near-Term GPS Range - The near-term GPS range has the same tracking radars and multilateration systems as shown in the non-GPS configuration. In theory, the non-GPS multilateration systems could be replaced with ground-based pseudolite stations; however, it would take 75 GPS stations since the GPS-based system has the same line-of-sight restrictions as the system it would replace. Therefore, it is not practical

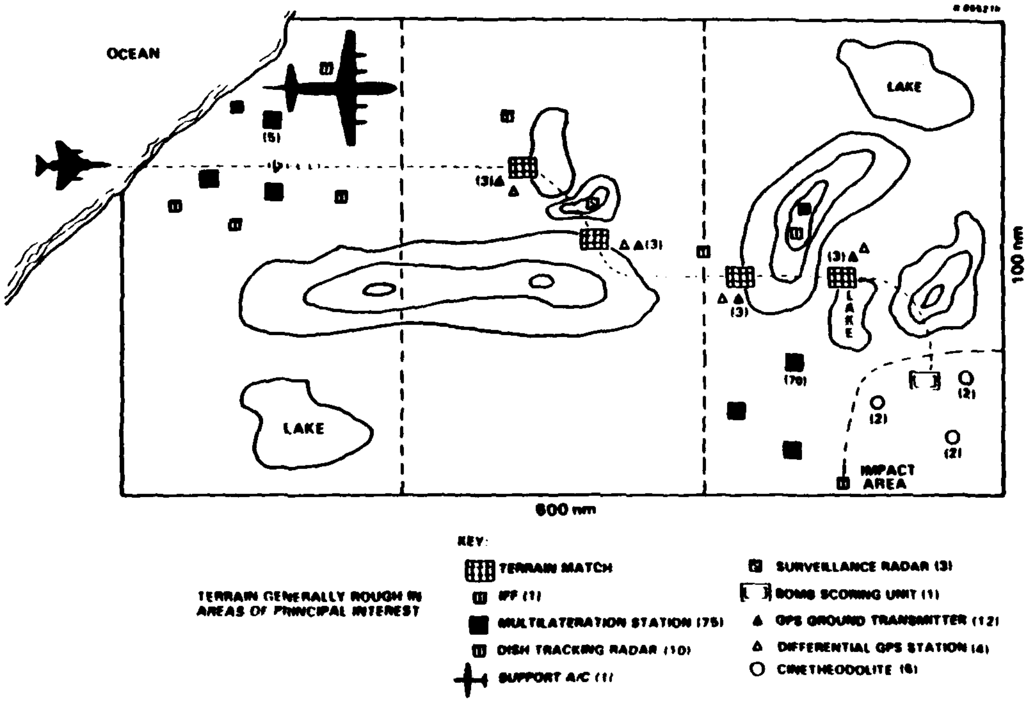


Figure 6.3-1 Low-Altitude, Extended-Range Weapons Generic Test Range: Near-Term GPS Option

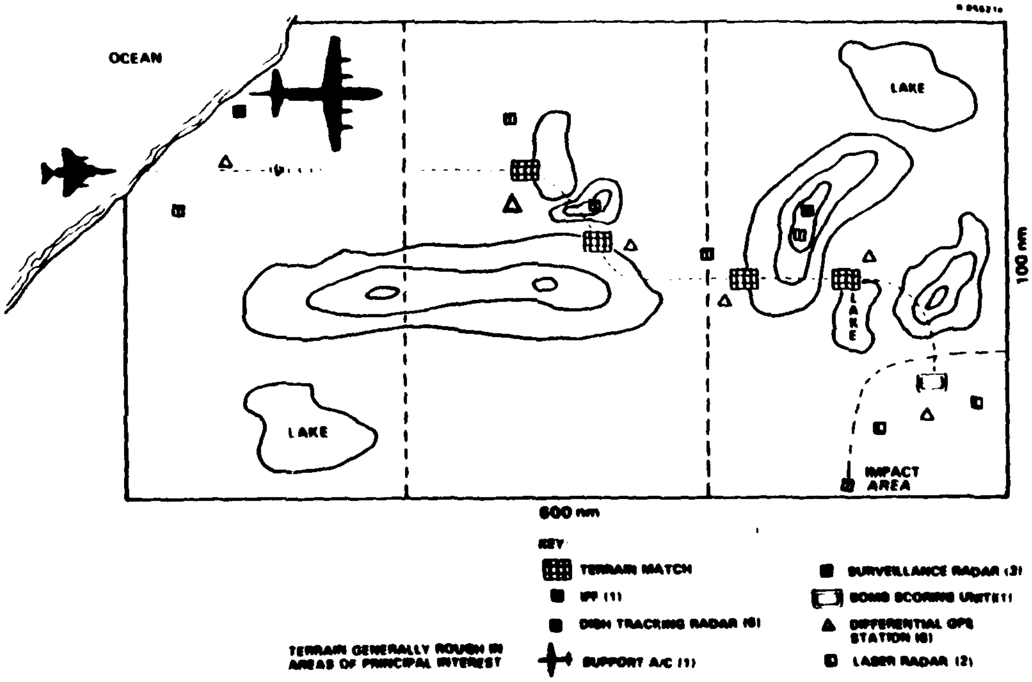


Figure 6.3-2 Low-Altitude, Extended-Range Weapons Generic Test Range: Far-Term GPS Option

to consider the latter option viable for the near-term. However, pseudolites are used to replace the cinetheodolites at the way points. A differential GPS station is provided to help meet the post-test position accuracy requirements.

Far-Term GPS Range - The far-term GPS range configuration will result in a significant reduction in instrumentation resources, since the multilateration systems may be removed. TSPI data may be relayed by or recorded on the support aircraft for cruise missiles or recorded on manned bombers. Differential receivers are spaced at way points, in the launch area, and in the terminal area, to support the post-test measurement accuracy requirements.

Table 6.3-1 lists the instrumentation for the near- and far-term non-GPS and GPS ranges. The range safety aspects of the range do not change. Surveillance radars, IFF, and support aircraft are required for any range configuration. As stated earlier, the multilateration stations are removed and GPS differential ground receivers added. The number of dish tracking radars is reduced simply because the need for "gap-filler" radars is eliminated due to the wide area measurement capability inherent in the far-term GPS range configuration.

6.3.2 GPS Range Capabilities

The TSPI capability of near- and far-term GPS ranges is shown in Table 6.3-2. These accuracy capabilities are based on the use of the C/A-code only. The post-test position accuracy requirements necessitate the use of a GPS differential ground receiver to remove the effects of ionospheric delays.

The near-term accuracy shown occurs only locally where pseudolites are placed in the launch area, at the way points,

TABLE 6.3-1

LOW-ALTITUDE, EXTENDED-RANGE WEAPONS
GENERIC TEST RANGE

NEAR-TERM INSTRUMENTATION OPTIONS

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Support A/C	1	1	Multilateration Stations	75	75
Dish Track Radar	10	10	GPS Ground Stations	12	---
IFF	1	1	GPS Differential Receivers	4	---
Surveillance Radar	3	3	Airborne GPS Translator Receiver	1	---
			Cinetheodolite	6	30

FAR-TERM INSTRUMENTATION OPTIONS

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Support A/C	1	1	Multilateration Stations	---	75
Dish Track Radar	6	10	GPS Differential Receivers	6	---
IFF	1	1	Airborne GPS Translator Receiver	1	---
Surveillance Radar	3	3			
Bomb Scoring Unit	1	1			
Laser Radar	2	6			

and in the scoring area. Wide-area coverage is provided by non-GPS systems and has the same accuracy as the non-GPS systems.

The far-term accuracy capabilities are identical to those for the near-term; however, the area of coverage is significantly improved. The far-term GPS range has the only instrumentation configuration that allows continuous coverage throughout the range. Furthermore, it provides altitude coverage down to ground level, providing there is no significant terrain masking of the satellites.

The accuracies shown in Table 6.3-2 are valid for both cruise missile and penetration bomber. The missile will

TABLE 6.3-2
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Low-Altitude, Extended-Range Weapons
Generic Test Category: Bomber, Cruise Missile
TSPI Configuration Number: 1 (Onboard C/A-Code Receiver - Differential Mode) - Bomber
3 (Onboard C/A-Code Translator - Differential Mode) - Cruise Missile

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy** (1σ)			
Position (x,y),(z) - ft	>100	30, 51	30, 51
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	10	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	20	20	20
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10	6, 10	6, 10
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1	0.02, 0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	1	‡	‡
• Number of Test Articles	1	N	N
• Coverage			
Altitude - kft	0.1 - 30	0.1 - 30	0 - 30
Distance - nm	100 x 600	100 x 600†	100 x 600

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Cruise missile only.

†Launch, way point and terminal areas

‡Requires dedicated impact scoring system

carry a low power translator to relay data to the support aircraft, which will carry a translator signal receiver. The bomber, however, will carry its own C/A-code five channel

receiver, and record TSPI data onboard the aircraft (see Figs. 3.4-1 and 3.4-3). If required, even better accuracy could be obtained by equipping the bomber with a five channel P-code receiver.

6.3.3 GPS Application Issues

To successfully develop a GPS instrumentation system for use on the Extended-Range Weapon generic range several issues must be addressed.

Antenna Masking - The instrumentation GPS receiver will require an antenna system which can maintain a line-of-sight to the GPS satellites, as well as to pseudolites wherever they are used. In the case of the cruise missile, a wraparound antenna can be placed around the missile so that antenna masking will be minimized. In the case of the bomber, antenna masking by the airframe may be reduced by using top- and bottom-mounted antennas. The effects of possible signal drop-outs due to antenna masking can be minimized through the use of an inertial system. This system can provide aiding to the GPS receiver to allow it to coast through those time periods where signals are lost so it can quickly reacquire following the outtage. Furthermore, the inertial information can be used as a source of TSPI data during the signal dropouts and still maintain the required accuracies.

Accuracy Issues - Table 6.3-2 shows that C/A-code instrumentation with differential ground receivers just meets the required vertical position accuracy. For bomber testing, reflections off the airframe could generate multipath errors larger than those predicted, resulting in an accuracy capability which does not meet requirements. If field tests show that this condition will occur, a P-code receiver could be used instead.

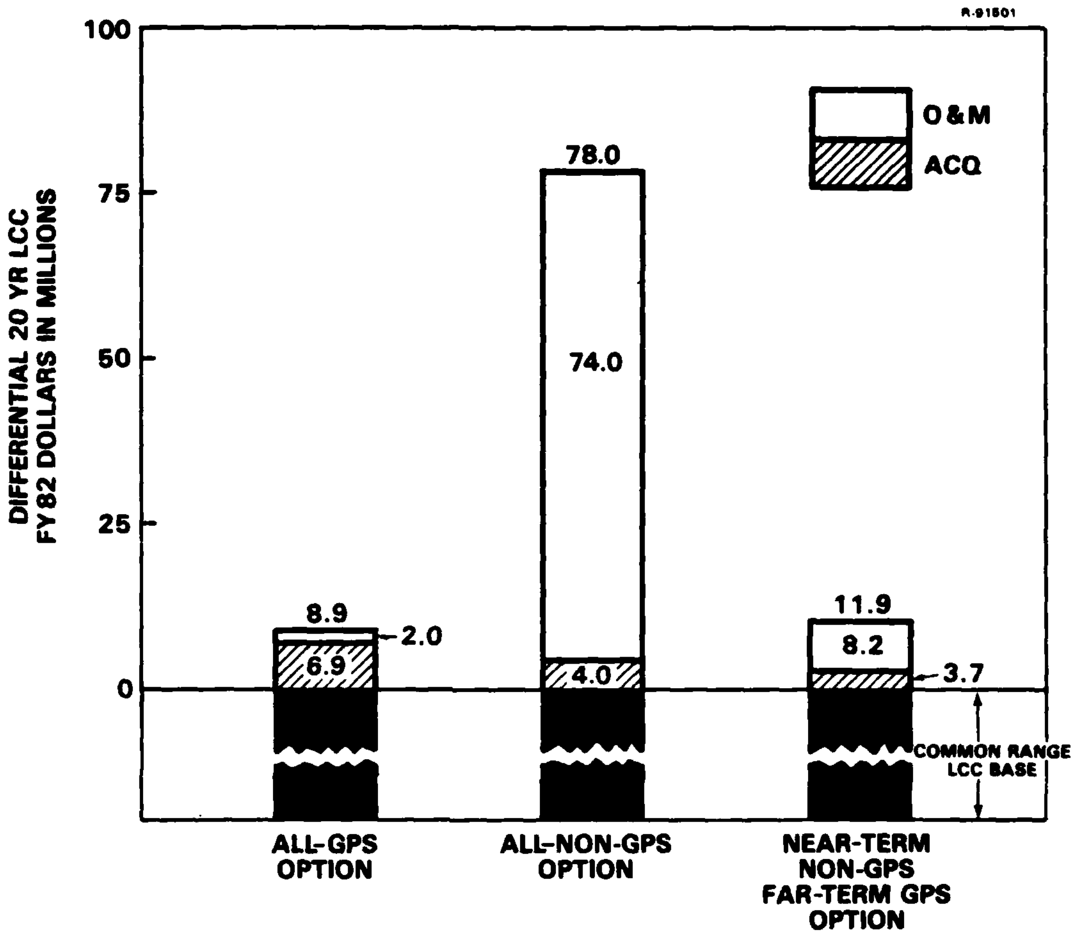
Interfacing - The GPS translator instrumentation must be mounted internal to the cruise missile, raising two major issues, packaging and power availability. Space must be provided for the low power C/A-code translator (approximately 30 in^3). Furthermore, a wraparound antenna must be integrated into the vehicle without disturbing its mechanical integrity. The warhead section could be used to accommodate the translator package and also provide the surface area necessary for the wraparound antenna. However, this assumes that sufficient volume will be available for the translator plus the telemetry and destruct systems. In addition, a transponder must be accomodated in the missile for near-term multilateration system operation.*

The power issue arises because the missile has to be modified to supply wiring from an onboard power source to the translator. An additional 50 watts at 28 volts is required for translator use.

6.4 LIFE-CYCLE COST COMPARISON

The differential 20-year life-cycle cost comparison of the all-GPS option versus the all-non-GPS option and mixed option is shown in Fig. 6.4-1. The analysis was based in the cost data presented in Section 4.2, coupled with the equipment buy numbers presented in Tables 4.2-1 and 6.3-1. The major contributors to cost in the all-GPS option are the development, acquisition and O&M of GPS range equipments, including inverted range items, and short-range translators for the test articles.

*For tests where cruise missiles are to be recovered, a parachute may also have to be accomodated.



- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based on Consolidated Buy

Figure 6.4-1 Low-Altitude, Extended-Range Weapons Range LCC Comparison

The all-non-GPS option costs are driven by the O&M of two multilateration systems and four dish tracking radars as well as the acquisition and O&M of four new laser radars in the far term. The costs for the mixed option reflect lower acquisition costs, because GPS equipments are not procured until the far term, and higher O&M costs, because the non-GPS multilateration systems are maintained through the near term.

The cost advantages of the GPS options over the non-GPS option are significant, as shown in Fig. 6.4-1. Given the relatively narrow band of uncertainty around unit costs, there is no reasonable set of circumstances that will decrease non-GPS-option costs and increase the GPS-options' costs by a large enough margin to change the conclusions that the GPS options are substantially less expensive.* For this range, any decision to commit to GPS in the near term is not clear-cut. There are some apparent savings, due to the avoidance of O&M of multilateration systems, which give the all-GPS option a slight edge over the mixed option. But the cost differential between the all-GPS and the mixed option ROM estimates is small enough that they should be considered essentially equal.

6.5 GPS RANGE EFFECTIVENESS EVALUATION

The effectiveness of the near- and far-term GPS ranges relative to the comparable non-GPS options is shown in Table 6.5-1. This table shows that both real-time and post-test accuracy requirements are only met by GPS instrumentation. Futhermore, the far-term GPS range configuration meets both low altitude and broad area coverage requirements, whereas the non-GPS range configuration does not. The near-term coverage capability of GPS and non-GPS ranges is equivalent since the GPS option also requires ground stations which are limited to locations around the way point and scoring areas.

In some areas, the qualitative "Consideration" Measures-of-Merit show no GPS advantage, mainly because ground stations are required in the near term for both configurations. One

*Costs were varied by ±25% for pseudolite acquisition and for multilateration system and dish radar O&M, with no significant change to the outcome.

TABLE 6.5-1

GPS COMPOSITE RANGE EFFECTIVENESS
SCREENING (LOW-ALTITUDE, EXTENDED-RANGE)

Generic Range: Low-Altitude, Extended-Range Weapons - DT&E, OT&E

Test Category: Cruise Missile, Bomber

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
DRIVERS:				
• REAL-TIME ACCURACY	+	+	Missile	Improved IIP Projections
• POST-TEST ACCURACY	+	$\boxed{+}$		Improved Inertial Guidance Analysis
• BROAD COVERAGE	0	+		
• LOW ALTITUDE COVERAGE	0	+		
• NUMBER OF PLAYERS	0	0		
• DATA RATE	0	0		
CONSIDERATIONS:				
• INTEGRATION	0	0		
• TECHNICAL RISK	$\boxed{-}$	$\boxed{-}$	Missile	Packaging Constraints
• GROWTH POTENTIAL	0	+		
• STANDARDIZATION	0	+		
• PORTABILITY	0	+		
• AVAILABILITY	0	+		
• DATA TIMELINESS	0	0		
GPS APPLICABILITY	Low	High	Accuracy and Coverage Mandate GPS	

*GPS VS NON-GPS OPTIONS

RATING KEY:
GPS BETTER +
GPS SAME 0
GPS WORSE -
CRTICIAL □

disadvantage of GPS is technical risk, (see Section 6.3.3), e.g., where antenna masking and packaging represent significant risks relative to a non-GPS range option. However, for the far-term configurations, standarization, portability and availability are enhanced with the GPS range option because of the significantly reduced ground resources needed for TSPI measurements. Growth potential is also improved with a GPS option

because the GPS velocity measurements offer a post-test accuracy capability of 0.02 - 0.03 fps, which provides a means to isolate error mechanisms within the vehicle inertial systems.

It is apparent upon inspection of Table 6.5-1 that the applicability of a far-term GPS range for use in testing low-altitude extended-range vehicles is very high since it meets the range accuracy and coverage requirements. The near-term applicability of a GPS range is not as clear, however. Improved real-time accuracy does provide enhanced measurements for IIP projections. However, the post-test velocity accuracy improvement is not of significant value since it is not continuous. Therefore, it cannot be used to its full potential in support of inertial system performance analysis. For these reasons, the near-term GPS applicability to range instrumentation is low.

7. SHORT-RANGE WEAPONS GENERIC LAND RANGE ANALYSIS

The generic land range used to support the DT&E and OT&E of all-altitude, short-range weapons is 150 nm long by 50 nm wide. It is divided into two distinct test areas: one which is geared to handle one-on-one testing and another for M-on-N testing. The former has two fully instrumented areas, the latter has one. Range topography is generally flat with surveillance radars on high ground. This range is primarily patterned after 5 DoD ranges: White Sands Missile Range (WSMR), Yuma Proving Grounds (YPG), Naval Weapon Center (NWC), Air Force Flight Test Center (AFFTC), and Armament Division (AD) and is used to test aircraft, drones, missiles, and land vehicles.

7.1 TSPI REQUIREMENTS ASSESSMENT

The requirements for the seven categories of weapon systems tested on the generic range are summarized in Table 7.1-1. Variations in the real-time requirements between test article types are indicative of the differences in range safety considerations associated with manned vehicles, unmanned vehicles operating in formation and guided missiles; as well as the post-test accuracies required. For example, both airborne drone and land vehicles, which are under manual control and in close proximity to other vehicles, have the tightest real-time position constraints. Next come missiles with somewhat lower constraints (S-A and S-S requirements vary with altitude), while manned aircraft requirements are least constraining. The latter two weapon categories could have even less restrictive requirements for range safety purposes; however, the real-time accuracies shown are driven by the post-test requirements.

TABLE 7.1-1
TSPI REQUIREMENTS*

Generic Range: All-Altitude, Short-Range Weapons Land Range

TEST PARAMETER	AIRCRAFT	DRONES	MISSILES				LAND VEHICLES
			A-A	A-S	S-A	S-S	
• Real-Time Accuracy (1σ)							
Position (x,y),(z) - ft	15-100	15-25	15-50	15-50	15-50	15-50	10-20
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	0.1-20	2	2	2	2-10	2-10	10
Timing (msec)	0.1	0.1	0.1	0.1	0.1	0.1	5
• Data Rate (#/sec)	10-50	10-50	10-100	10-100	10-100	10-100	1-20
• Post-Test Accuracy (1σ)							
Position (x,y),(z) - ft	2-15	2-15	2-15	2-15	2-15	2-15	5-15
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) -fps	0.01-10	2-10	2-10	1-10	2-10	1-10	10
• Scoring Accuracy (ft-1σ Circ)	---	---	1-2	1-5	1-5	1-10	---
• Number of Test Articles	4	6	6	12	4	6	12
• Coverage							
Altitude - kft	0-100	0-60	0-60	0-75	0-60	0-40	0
Distance - nm	250	50	50	50	50	50	5

*Parameter ranges, where specified, reflect differing requirements for each test phase.

The post-test position requirements for weapon system evaluation vary from stringent to relatively lax for all test categories (depending on the test phase) while both real-time and post-test velocity requirements are generally lose. Exceptions to the latter are the precise aircraft velocity needed for the evaluation of avionics systems and the somewhat tighter A-S and S-S missile velocity requirements which are useful for submunitions and flight model verification.

The last accuracy area to be considered, scoring, imposes the most stringent requirements on an instrumentation system with the accuracy needed inversely proportional to the size of the warhead. However, these accuracies (usually relative) are typically met by optical systems such as cinetheodolites or specialized scoring instrumentation rather than systems with broader tracking capabilities such as radars or multilateration systems.

In addition to the accuracy parameters discussed, the generic range must also satisfy requirements for data rate, number of test articles supported, and coverage. Data rate requirements are functions of vehicle dynamics, i.e., land vehicles are lowest, aircraft and drones higher, and missiles highest. The 100 pps requirements, however, are driven only by end game requirements and may require special instrumentation.

Numbers of test articles which must be maintained under track, on the other hand, are test scenario dependent. For example, the requirement for 12 A-S and land vehicles represent WASP scenarios, while a combination of 4 aircraft, 6 target drones and 6 A-A missiles is representative of AMRAAM-type test engagements (although it's questionable whether a medium range missile, such as AMRAAM, will ever be tested in a large M-on-N scenario over the Land Range). A final example

of the scenario-dependent requirements may be found in the 6 S-S missile requirement which is needed for MLRS ripple fire scenarios.

Coverage requirements, in contradistinction to the scenario drivers for the number of vehicles, are functions of the operating range and altitude of the vehicle, i.e., aircraft require the greatest coverage followed by shorter range weapons like drones and missiles. Land vehicles, particularly target drones, require the least. In all cases, coverage down to ground level is desired.

7.2 GENERIC NON-GPS RANGE BASELINES

The type and function of the near- and far-term non-GPS instrumentation used on the generic Short-Range Weapon Land Range is described in this section. Also covered is a discussion of the range's capability relative to the TSPI requirements.

7.2.1 Instrumented Range Description

Near-Term Non-GPS Range- The complement of non-GPS-based TSPI instrumentation for the near term is shown in Fig. 7.2-1. For one-on-one testing in the two test areas, tracking is performed with a combination of five dish radars, three angle-only optical trackers with laser range finders, and fifteen optical trackers without laser range finders. The dish radar trackers provide longer range all-weather tracking capabilities of single objects, while the optics supply more precise tracking to meet tighter post-test accuracy and scoring requirements. The relatively large number of single optical trackers gives redundancy for backup purposes to help ensure reasonable geometry will be available to at least 2 of the

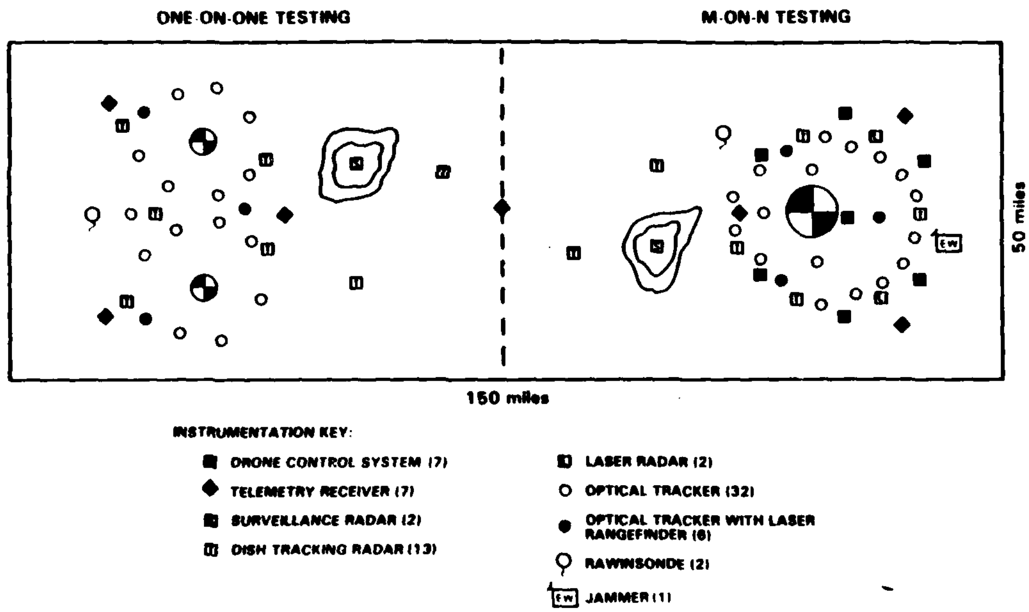


Figure 7.2-1 All-Altitude, Short-Range Weapons Generic Land Test Range: Near-Term Non-GPS Option

angle-only trackers. Telemetry receivers are available in sufficient numbers throughout the entire generic range to provide for line-of-sight (LOS) constraints. Four dish tracking radars are distributed in the middle of the range to provide coverage for aircraft testing, which may involve the entire range. Surveillance radars on high ground perform the range-safety function for non-cooperative targets.

The area for M-on-N testing is instrumented with a multilateration system for drone control (both airborne and land-based) and multiple object tracking in addition to a number of single object trackers. The latter are composed of four dish and two laser radar trackers, three angle-only optical trackers with laser range finders, and seventeen angle-only

optical trackers. The laser radars add precision instrumentation for tracking and scoring purposes which can provide data in essentially real-time.

Far-Term Non-GPS Range - The instrumentation layout for the far-term non-GPS range is shown in Fig. 7.2-2. Two multiple target tracking, phased array radars have replaced five less-efficient dish radars in the two one-on-one testing areas. Also, five laser radars have supplanted fifteen angle-only optical trackers and three optical angle trackers plus laser rangefinders in the same areas. The latter upgrade not only eliminates the costly manual processing associated with the optical system but simplifies the planning and handover problem associated with the large array of optical sensors (although handover is still required for the narrow beam laser).

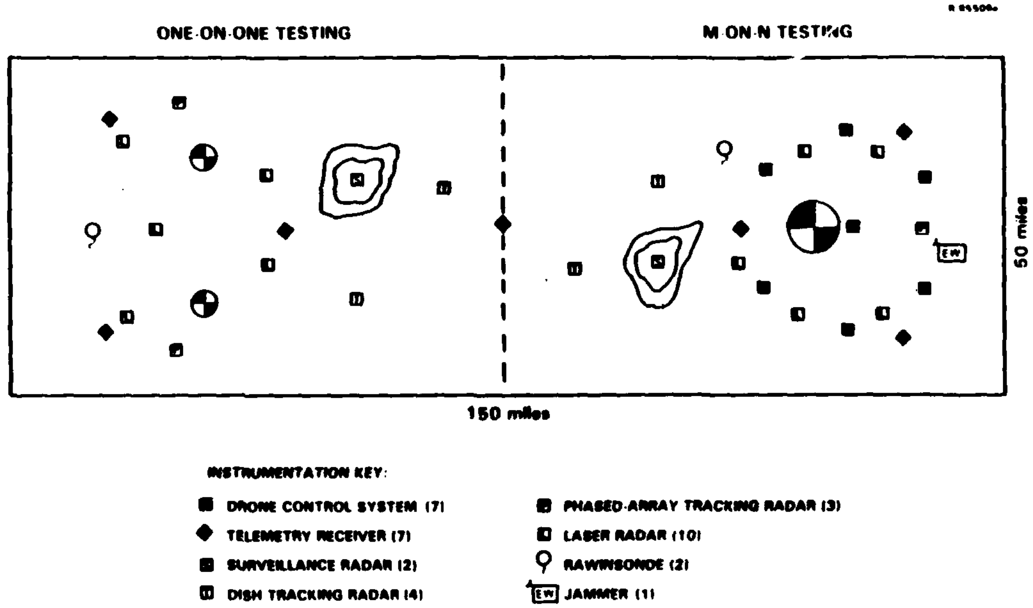


Figure 7.2-2 All-Altitude, Short-Range Weapons Generic Land Test Range: Far-Term Non-GPS Option

In the M-on-N testing area, a single phased array radar replaces the 4 dish radars to provide additional multi-object tracking capability. In addition, 3 laser radars were added to the 2 existing ones to provide the resources to replace the 17 angle-only optical trackers and 3 angle-only optical trackers plus laser range finders. The four mid-range dish radars were left to support tracking in that area.

7.2.2 Non-GPS Range Capabilities

The non-GPS range capabilities and requirements for each test category are summarized in Tables 7.2-1 through 7.2-4. Real-time position accuracies typically vary from 15 to 50 ft in x and y and from 15 to 200 ft in z, depending upon the range of the test article with respect to the radars, or the test article altitude and geometry with respect to the multilateration stations. Because real-time velocity is derived from position measurements, velocity performance varies accordingly. The range of post-test accuracy capabilities shown in the tables tends to reflect that associated with short-range, good geometry tracking rather than that generally available over the entire range.

Data rate capabilities range from 10 to 100 pps on most vehicles with the lower bound typical of multilateration systems and the higher typical of radars. Similar qualifiers may be place on other TSPI parameters. For example, the ability to track up to 10 airborne vehicles simultaneously in the near term is typical of multilateration system capabilities (for nominal data rates of 10 pps) while the combined dish and phased array radars add the higher capability. Finally, coverage is a variable which depends both upon the tracking instrumentation used (i.e., lasers and optics are typically limited by atmospheric conditions to ranges of 50 kft or less while radars

TABLE 7.2-1
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Aircraft

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY
• Real-Time Accuracy (1σ)		
Position (x,y),(z) - ft	15-100	15-50, 15-200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-20	2-10, 2-50
Timing (msec)	0.1	0.1
• Data Rate (#/sec)	10-50	10-50
• Post-Test Accuracy (1σ)		
Position (x,y),(z) - ft	2-15	1-5†
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.01-10	0.1-1†
• Scoring Accuracy (ft-1σ Circ)	---	---
• Number of Test Articles	4	10**
• Coverage		
Altitude - kft	0-100	0-100
Distance - nm	250	10-250

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Total of 10 airborne vehicles in near term, greater than 10 in far term.

†Position accuracy of 3-15 ft and velocity accuracy of 15 fps over most portion of the range.

and multilateration systems can cover much larger areas), and the altitude of the airborne vehicle. However, for ground-based vehicles, line-of-sight limitations serve to limit coverage.

TABLE 7.2-2
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Drones

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY
• Real-Time Accuracy (1σ)		
Position (x,y),(z) - ft	15-25	15-50, 15-200
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2	2-10, 2-50
Timing (msec)	0.1	0.1
• Data Rate (#/sec)	10-50	10-50
• Post-Test Accuracy (1σ)		
Position (x,y),(z) - ft	2-15	1-5
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2-10	0.1-1
• Scoring Accuracy (ft-1σ Circ)	---	---
• Number of Test Articles	6	10†
• Coverage		
Altitude - kft	0-60	0-40
Distance - nm	50	10-50

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Total of 10 airborne vehicles in near term, greater than 10 in far term.

A comparison of non-GPS range capabilities and requirements shows deficiencies in several areas. For aircraft, these deficiencies include real-time z accuracy (at lower altitudes), insufficient velocity accuracy (real-time and post-test) for avionics testing, and coverage. For drones, similar problems exist with the exception of velocity accuracy. The greatest

TABLE 7.2-3

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range

TEST PARAMETER	REQUIREMENTS		CAPABILITIES	REQUIREMENT	CAPABILITY	REQUIREMENT	CAPABILITY
	A-A	A-S	A-A, A-S	S-A	S-A	S-S	S-S
• Real-Time Accuracy (1σ)							
Position (x,y),(z) - ft	15-50	15-50	15	15-50	15-50	15-50	15-50
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2	2	2	2-10	2-10	2-10	2-10
Timing (msec)	0.1	0.1	0.1	0.1	0.1	0.1	0.1
• Data Rate (#/sec)	10-100	10-100	10-100	10-100	10-100	10-100	10-100
• Post-Test Accuracy (1σ)							
Position (x,y),(z) - ft	2-15	2-15	1-5	2-15	1-5	2-15	1-10
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2-10	1-10	0.1-1	2-10	0.1-1	1-10	0.1-2
• Scoring Accuracy (ft-1σ Circ)	1-2	1-5	1	1-5	1	1-10	1
• Number of Test Articles	6	12	$\geq 10^{\dagger}$	4	$>10^{\dagger}$	6	$>10^{\dagger}$
• Coverage							
Altitude - kft	0-60	0-75	0-40	0-60	0-40	0-40	0-40
Distance - nm	50	50	10-50	50	10-50	50	10-50

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Total of 10 airborne vehicles in near term, greater than 10 in far term.

TABLE 7.2-4

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Land Vehicles

TEST PARAMETER	TSPI† REQUIREMENT	NON-GPS TSPI CAPABILITY†
• Real-Time Accuracy (1σ)		
Position (x,y),(z) - ft	10-20	10
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10	10
Timing (msec)	5	5
• Data Rate (#/sec)	1-10	1-3
• Post-Test Accuracy (1σ)		
Position (x,y),(z) - ft	5-15	5-10
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10	5-10
• Scoring Accuracy (ft-1σ Circ)	---	---
• Number of Test Articles	12	12
• Coverage		
Altitude - kft	0	0
Distance - nm	5	5

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Parameter values are a composite of stated range values and engineering judgement.

shortcoming for missile TSPI performance lies in the area of coverage, although in the near term, the limitation of 10 airborne vehicles might prove stressing in air-to-air scenarios. Finally, the range capabilities for land vehicles match the requirements except for the upper bound on data rate. As a

practical matter, however, a data rate of 3 pps should be adequate for most vehicle tracking needs.

7.3 GPS SCENARIO DEVELOPMENT

This section defines the near- and far-term GPS ranges and the rationale for their development. The selection of a GPS-based TSPI configuration for each test article is described along with a comparison of anticipated performance and capabilities. Finally, a discussion of GPS application issues is provided.

7.3.1 Instrumented GPS Range Description

The development of the near-term GPS range option (shown in Fig. 7.3-1) was based on its non-GPS counterpart. All non-GPS instrumentation was retained with the exception of the seven multilateration stations on the M-or-N testing portion of the range. They were replaced with a like number of GPS pseudolites (which include a data link for the C^2 function) under the premise that the pseudolite and multilateration station have similar LOS constraints. Other changes from the near-term non-GPS baseline include the addition of GPS-specific ancillary range equipment in the form of a differential receiver station (to enhance tracking accuracy) and a set of twelve translator receivers deployable at the pseudolite/C^2 station sites. Finally, a geoceiver and timing receiver were added to the complement of range equipment to take advantage of the precise survey and timing data available with GPS.

The far-term GPS range configuration shown in Fig. 7.3-2 reflects the simplifications possible with the continuous availability of GPS data at all points on the range. The need for multiple tracking, phase array radars was eliminated along with

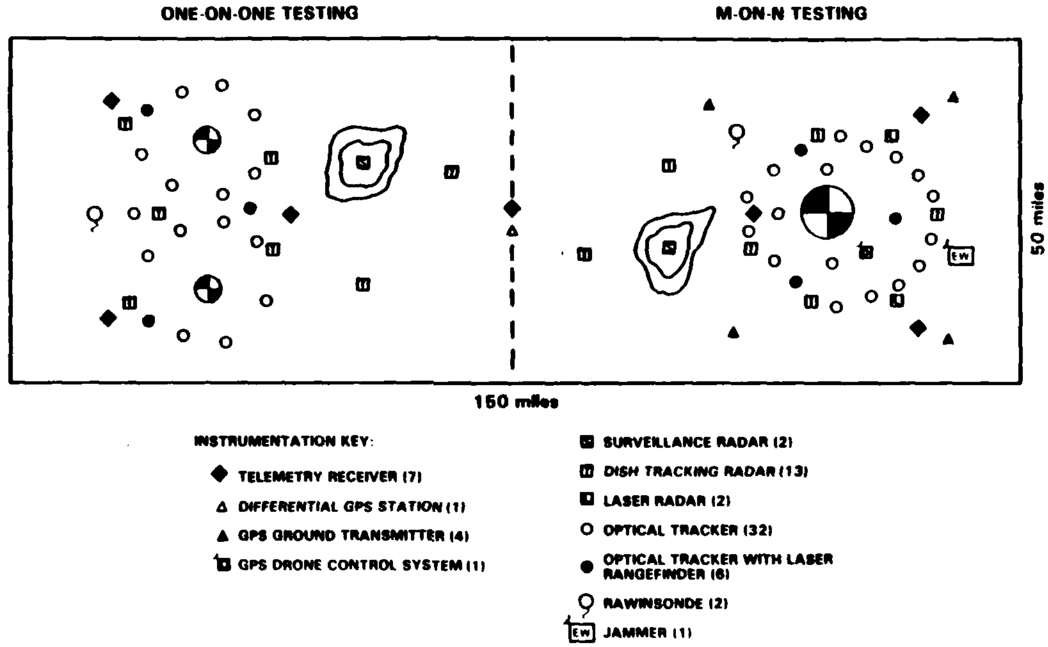


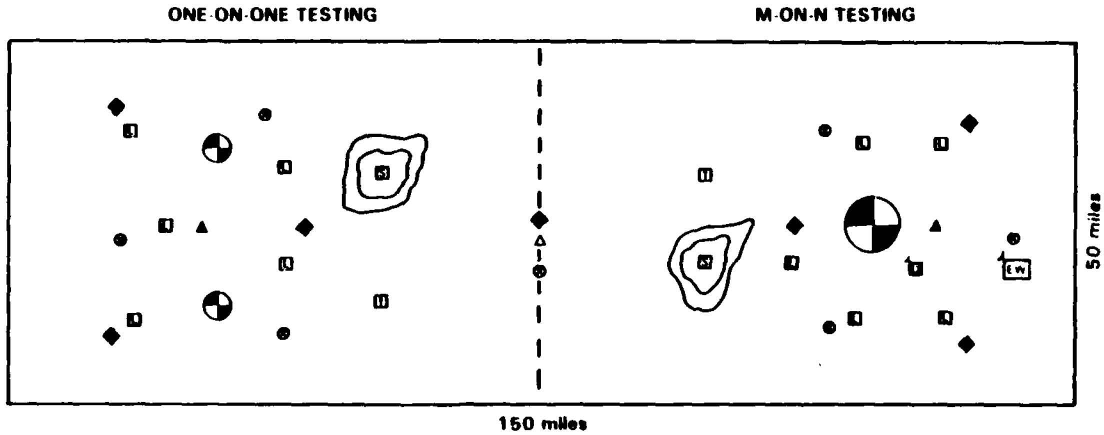
Figure 7.3-1 All-Altitude, Short-Range Weapons Generic Land Test Range: Near-Term GPS Option

four of the pseudolites. However, three of the seven pseudolite/ C^2 stations were retained to provide GDOP enhancement and to serve as an adjunct for scenarios in which L-band jamming might be employed against systems such as GPS, JTIDS, IFF, etc. Also retained were two of the dish radar trackers (as backups and signature radars) and surveillance radars needed for the track of non-cooperative targets entering the range area. Other changes with respect to the near-term range include the deletion of the optical trackers and their replacement with laser radars, the addition of a differential receiver station (to provide a second source of corrections) to cover the entire range, and the redistribution of translator signal receivers for the same reason.

Table 7.3-1 provides a comparative summary of the non-GPS and GPS instrumentation options.

TEST CATEGORIES:

- AIRCRAFT
- DRONES
- LAND VEHICLES
- A-A MISSILES
- A-S MISSILES
- S-A MISSILES



PATTERN RANGES:

- WSMR
- YPG
- NWC
- AFFTC
- AD

Figure 7.3-2 All-Altitude, Short-Range Weapons Generic Land Test Range: Far-Term GPS Option

7.3.2 GPS Range Capabilities

GPS configurations were chosen for each test category based on the TSPI requirements and other considerations such as vehicle expendability or size (see Section 3.4 for configuration description). In several instances (such as small missiles), the available volume alone dictated the choice of GPS TSPI equipment. Because GPS TSPI capabilities are sensitive to the choice of equipment, a requirements vs GPS capabilities chart was prepared for each test category to determine the performance ramifications.

Aircraft - Aircraft may utilize three of the four configurations defined in Section 3.4 depending upon operational receiver availability and the testing scenarios. For

TABLE 7.3-1

INSTRUMENTATION OPTIONS COMPARISON - SHORT-RANGE WEAPONS LAND RANGE

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	7	GPS Equipment		
Drone Control Station	1	1	Pseudolite*	7	---
Tracking Radar			Differential Station	1	---
Dish	13	13	Translator Receiver	12	---
Laser	2	2	Geoceiver	1	---
Optical Tracker			Timing Receiver	2	---
With Laser Rangefinder	6	6	Surveillance Radar	2	2
Without Laser Rangefinder	32	32	Test Article Equipment	Yes	Yes

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	7	GPS Equipment		
Drone Control Station	1	1	Pseudolite*	3†	---
Tracking Radar			Differential Station	2	---
Dish	2	4	Translator Receiver	12	---
Phased Array	---	3	Geoceiver	1	---
Laser	10	10	Timing Receiver	1	---
			Surveillance Radar	2	2
			Test Article Equipment	Yes	Yes

example, Configuration 1 employing an onboard or pod-mounted receiver and Configuration 2 using an onboard receiver plus 1553 data bus are suitable for M-on-N testing where bandwidth availability may be limited due to the simultaneous use of translators on small vehicles. These configurations have the added advantage that P-code may be utilized for additional accuracy and jam resistance. However, for one-on-one testing, the onboard or pod-mounted C/A-code translator (Configuration 3) may offer a cheaper alternative than the receiver. (Although

a translator receiver is still required to process the translated signals, its availability is mandated anyway to support the evaluation of small test articles.) The only potential problem with C/A-code in this application is a reduction in available position accuracy, which for aircraft means failure to meet the lower bound on this requirement's parameter (see Table 7.3-2).

TABLE 7.3-2
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Aircraft

TSPI Configuration Numbers:
1. (Onboard or Pod P-Code Receiver - Differential Mode)
2. (Pod Plus Operational P-Code Receiver - Differential Mode)
3. (Onboard or Pod C/A-Code Translator - Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY			
		NEAR TERM (RECEIVER)	FAR TERM (RECEIVER)	NEAR TERM (TRANSLATOR)	FAR TERM (TRANSLATOR)
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	15-100	7,12	7,12	25,41	25,41
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-20	0.06,0.11†	0.06,0.11†	0.06,0.11	0.06,0.11
Timing (msec)	0.1	0.0001	0.0001	0.0001	0.0001
• Data Rate (#/sec)	10-50	10-50†	10-50†	10-50†	10-50†
• Post-Test Accuracy (1σ)					
Position (x,y),(z) - ft	2-15	2-4	2-4	6-10	6-10
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.01-10	0.02,0.03	0.02,0.03	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	---	---	---	---	---
• Number of Test Articles	4	Unlimited**	Unlimited**	>4	>4
• Coverage					
Altitude - kft	0-100	0-100††	0-100+	0-100††	0-100+
Distance - nm	250	10-250	250+	10-250	250+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Potentially limited by telemetry capacity only.

†With IMU.

††Two or more satellites available 12-17 hrs. per day for z data.

Drones - Different near- and far-term configurations (3 and 1 respectively) were chosen for drone applications because of expected volume constraints. In the near term, the onboard C/A-code translator was selected because of its compact size (≤ 30 in^3) while in the far term, technological growth coupled with advanced digital design is expected to produce a multi-channel P-code receiver which could conform to volume limitations. The performance impact of these selections is reflected in Table 7.3-3, which presents a GPS performance comparison with drone TSPI requirements. As the table indicates, C/A-code operation degrades positioning performance which, in real-time, is particularly important for drone control. Therefore, P-code receivers should be considered wherever they can be accomodated.

Missiles - The onboard translator (Configuration 3) appears to be the only GPS solution for most short-range missile applications in the near and far term. However, as the size of available P-code receivers shrinks in the far term with technological advances, it is anticipated that receivers may fit aboard some of the larger short-range missiles. Referring to Table 7.3-4, several conclusions become obvious. First, C/A-code translators provide marginal position accuracies relative to the requirements. Second, high data rates will not be possible without IMU data which for small missiles may not be available. Third, the ability of translators to support the A-S missile number requirement of twelve is strictly a function of available bandwidth allocation. Changing to a receiver, where possible, will alleviate the accuracy and number deficiencies, but not the data rate problem.

Land Vehicles - The use of an onboard P-code receiver (Configuration 1) will provide the accuracy needed to meet the TSPI requirements for land vehicles (see Table 7.3-5. However,

TABLE 7.3-3

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Drones

TSPI Configuration Number:
1. (Onboard or Pod P-Code Receiver - Differential Mode)
2. (Pod Plus Operational P-Code Receiver - Differential Mode)
3. (Onboard or Pod C/A-Code Translator- Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM (TRANSLATOR)	FAR TERM (RECEIVER)
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - fT	15-25	25,41	7,12
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2	0.06,0.11†	0.06,0.11†
Timing (msec)	0.1	0.0001	0.0001
• Data Rate (#/sec)	10-50	10-50†	10-50†
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	2-15	6,10	2,4
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2-10	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	---	---	---
• Number of Test Articles	6	6	6**
• Coverage			
Altitude - kft	0-60	0-60††	0-60+
Distance - nm	50	10-50	50+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Potentially limited by telemetry capacity only.

†With IMU.

††Two or more satellites available 12-17 hrs per day for "z" data.

data rates available from a single or dual channel receiver (typically 1 pps or less) will not meet the upper requirements bound of 10 pps. This deficiency may be rectified by using an external source of velocity data such as a vehicle dead reckoning navigation system if available.

TABLE 7.3-4
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Missiles (A-A, A-S, S-A, S-S)

TSPI Configuration Number: 4. (Onboard C/A-Code Translator - Differential Mode) - Near Term, Far Term
1. (Onboard P-Code Receiver - Differential Mode) - Far Term Only

TEST PARAMETER	TSPI REQUIREMENTS				GPS TSPI CAPABILITY		
	A-A	A-S	S-A	S-S	NEAR TERM (TRANSLATOR)	FAR TERM (TRANSLATOR)	NEAR TERM (RECEIVER)
• Real-Time Accuracy (1σ)							
Position (x,y),(z) - ft	15-50	15-50	15-50	15-50	25,41	25,41	7,12
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	2	2	2-10	2-10	0.06,0.11†	0.06,0.11†	0.06,0.11†
Timing (msec)	0.1	0.1	0.1	0.1	0.0001	0.0001	0.0001
• Data Rate (#/sec)	10-100	10-100	10-100	10-100	10-50†	10-50†	10-50†
• Post-Test Accuracy (1σ)							
Position (x,y),(z) - ft	2-15	2-15	2-15	2-15	6-10	6-10	2,4
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	2-10	2-10	2-10	1-10	0.02,0.03	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	1-2	1-5	1-5	1-10	---	---	5
• Number of Test Articles	6	12	4	6	≥6	≥6	Unlimited
• Coverage							
Altitude - kft	0-60	0-75	0-60	0-40	0-75**	0-75+	0-75+
Distance - nm	50	50	50	50	10-50	50+	50+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Two or more satellites available 12-17 hrs. per day for z data.

†With IMU.

7.3.3 GPS Application Issues

A number of issues pertaining to GPS test article equipment must be resolved before implementation can be considered. These issues may be categorized as those impacting either performance or the form fit factor of the vehicle. The following discussion treats both categories where suitable.†

†General implementation issues such as the synchronization of translator and IMU data and P- vs C/A-code issues were covered in Section 3.1 and are not be repeated here.

TABLE 7.3-5
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short Range Weapons Land Range (DT&E, OT&E)

Generic Test Category: Land Vehicles

TSPI Configuration Number: 1 (Onboard P-Code Receiver - Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	10-20	7,12	7,12
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10	0.06-0.11	0.06-0.11
Timing (msec)	5	0.0001	0.0001
• Data Rate (#/sec)	1-10	$\leq 1^{\dagger}$	$\leq 1^{\dagger}$
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	5-15	2,4	2,4
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	10	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	---	---	---
• Number of Test Articles	12	12	12
• Coverage			
Altitude - kft	0	0	0
Distance - nm	5	5+	5+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†For low dynamic receiver without inputs from an on-board velocity source.

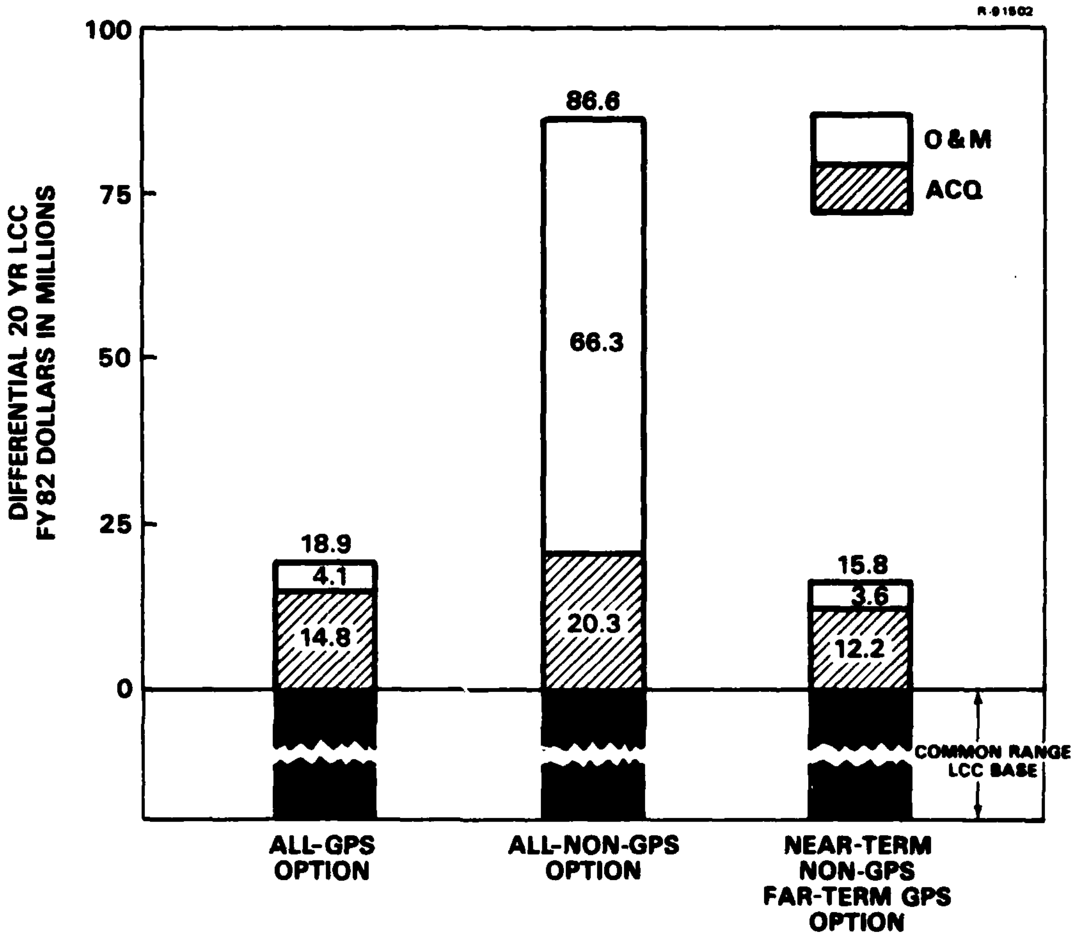
Translators - Applications require compact, low power translators geared to those vehicles which are volume limited, have small diameters and may be expendable. The first and third characteristics have implications with respect to IMU

availability and acceptable cost levels, respectively. In contradistinction, vehicle diameter tends to limit the available transmit and receive antenna gains of the TSPI device. Two other major issues concerning translator applications are the operational power which must be supplied by the vehicle, since up to 50 W may be needed for the translator and 75 W for the IMU (if not already part of the vehicle configuration); and the allocated bandwidth for the translator signals to permit a relatively high number of participants to broadcast at the same time.

Receivers - Several of the same issues raised for translators are of concern for receiver applications to small vehicles. In fact, receiver volume and power requirements place an even larger burden on small vehicles. Even on larger vehicles like aircraft, pod-mounting places the same type of small diameter constraints on the antenna. In addition, typical under-wing pod station configurations impose the additional constraint of wing and fuselage masking upon satellite line-of-sight availability. This problem may be alleviated with wing-mounted conformal antennas or longer pods, although neither is currently available.

7.4 LIFE-CYCLE COST COMPARISON

The differential 20-year life-cycle cost comparison for the Short-Range Weapons Land Generic Range, is shown in Fig. 7.4-1 based on the cost data provided in Section 4.2. The major contributors to cost in the all-GPS option are GPS equipment development, acquisition and O&M, including inverted range items plus test articles, low power translators and multichannel receivers (Table 4.2-1 summarizes the translator/receiver equipment numbers).



- Federated Drone Control/Multilateration
- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based On Consolidated Buy

Figure 7.4-1 All-Altitude, Short-Range Weapons Land Range LCC Comparison

The all-non-GPS option costs are driven by the acquisition of user equipment transponders, the O&M of dish radars retained in the far term, and the acquisition and O&M of three single-faced, phased array radars in the far term. The costs for the mixed option reflect lower acquisition and O&M costs

because GPS equipments are not purchased and maintained until the far term.

Figure 7.4-1 portrays a decided advantage to the GPS options over the non-GPS option. There is no reasonable variation in equipment cost or buy size which can reduce the all-non-GPS option costs and raise the GPS-options costs by a large enough margin to materially affect the conclusion that GPS options are significantly less expensive.* However, the size of the cost differential between the all-GPS option and the mixed option is not large enough to state that the mixed option is the most advantageous based on cost alone.

7.5 GPS RANGE EFFECTIVENESS EVALUATION

GPS effectiveness for the near- and-far term instrumentation options was assessed for seven test categories of weapons supported by the Short-Range Weapons Land Range:

- Aircraft
- Drones
- Missiles (A-A, A-S, S-A, S-S)
- Land Vehicles

An example of such an assessment, as performed for aircraft testing, is shown in Table 7.5-1. In this table, GPS was given a "+" in the near and far term for real-time and post-test

*Sensitivity analyses were performed by varying GPS translator, GPS receiver phased array radar and dish radar acquisition and O&M cost by ±25%. Translator and receiver quantities were varied from nominal values used in these calculations to maximum and minimum values based on the spread evidenced in historical range usage.

accuracy because of the importance of precise velocity data in the evaluation of aircraft avionics systems. An additional benefit derived from GPS in the capability of meeting the "z" tracking requirement most of the time in the near term (at least 2 satellites are available approximately 17 hrs a day) and continuously in the far term. The other "Driver" benefit provided by GPS is broad coverage over the entire Land Range in the far term (required for aircraft only), which the non-GPS option can not meet.

The evaluation of "Considerations" MOMs produced both positive and negative ratings. Positive factors in favor of GPS include a reduction in the number of interfaces (simplifying integration since "z" aiding is not required), and standardization advantages accruing from GPS as a single source of high quality TSPI data. The latter leads to an improvement in availability since less reliance need be placed on multiple ground-based TSPI equipments. Finally, GPS can eliminate dependence on labor-intensive optics processing used to obtain precision velocity estimates which can, in turn, reduce turn-around-time for quick-look and post-mission assessment.

Negative ratings for GPS appear in the area of technical risk and integration. Under technical risk, the negative rating was assigned because of a potential problem (to be evaluated in a special test program) with GPS pod antenna blockage, which may be exacerbated by a need for simultaneous satellite and pseudolite tracking. However, this problem may be alleviated to a satisfactory degree with a pod extension or a conformal wing panel-mounted antenna. Although the application of an aircraft's operational receiver and antenna as a TSPI source may also circumvent this particular pod-associated problem, TSPI system integration may still be complicated by the requirement to interface the operational GPS receiver and pod if the aircraft is not equipped with a 1553 data bus.

TABLE 7.5-1

GPS RANGE EFFECTIVENESS

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)
Test Category: Aircraft

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM	
DRIVERS:			
• Real-Time Accuracy	+	+	
• Post-Test Accuracy	+	+	
• Broad Coverage	0	+	Improved Velocity With Aided GPS
• Low Altitude Coverage	0	+	
• Number of Players	0	0	
• Data Rate	0	0	GPS Needs Aiding For 50 Hz
CONSIDERATIONS:			
• Integration	0	+, -	No "z" Aiding, Operation Receiver W/O 1553 (Can Use Pod Set)
• Technical Risk	-, 0	-, 0	Pod Antenna Blockage, Operational or Wing Panel Antenna
• Growth Potential	0	0	
• Standardization	0	+	Single TSPI Source
• Portability	0	0	
• Availabilty	0	+	Less Reliance on Older Equipment
• Data Timeliness	+	0	Labor Intensive Optics for Velocity
GPS APPLICABILITY	HIGH	HIGH	Accuracy and Coverage in Far Term

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

A composite effectiveness evaluation for all the test categories associated with the generic range is given in Table 7.5-2. This table reflects the commentary given above for the aircraft as well as that for other test categories. For example, drones were given a "+" for real-time accuracy in the far term but not in the near term, because of the assumption that a multi-channel P-code receiver could not be accomodated on most drones in the near term, leaving C/A-code translators as the only alternative. The future availability of a low volume, multi-channel P-code receiver in the far term also led to a "+" under growth potential for drones because of the tighter formations possible.

TABLE 7.5-2

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Test Category: Aircraft, Drones, Missiles (A-A, A-S, S-A, S-S), Land Vehicles

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE* NEAR TERM	GPS RELATIVE ADVANTAGE* FAR TERM	PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
DRIVERS:				
• Real-Time Accuracy	$\boxed{+}$	$\boxed{+}$	Aircraft, Drones (F)	Better Velocity
• Post-Test Accuracy	$\boxed{+}$	$\boxed{+}$	Aircraft	
• Broad Coverage	0	+	Aircraft, Drones, Missiles	Data Link LOS Restrictions Only
• Low Altitude Coverage	+	+	Aircraft, Drones, Missiles	
• Number of Players	0, -	0, -	A-S WASP Missile	Possible Translator BW Limits
• Data Rate	0, -	0, -	Drone, Missile (W/O IMU)	20-30 Hz W/O IMU
CONSIDERATIONS:				
• Integration	0	+	Aircraft, Drones	No "Z" Aiding
• Technical Risk	$\boxed{-}$	$\boxed{-}$	Aircraft, Missile, Drones(F)	Antenna Blockage; Translator Issues
• Growth Potential	0	+	Drones	Precise Formations
• Standardization	0	+	Aircraft, Drones, Missiles	Fewer TSPI Sources
• Portability	0	0		
• Availability	0	+	Aircraft, Drones, Missiles	Less Reliance on Older Equipment
• Data Timeliness	+	0	Aircraft	Labor Intensive Optics Avoided
GPS APPLICABILITY	HIGH	HIGH	Coverage and Accuracy in Far Term	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

For missile applications, C/A-code translators present limitations on the number of players and potential technical risk. For example, WASP's requirements for 12 simultaneous tracks might not be met with GPS because of potential translator bandwidth (BW) limitations, although other missile types will probably not be so constrained. Nevertheless, technical risks may be posed for missiles because of questions such as real-time aiding and GPS antenna gains.

8. SHORT-RANGE WEAPONS GENERIC WATER RANGE ANALYSIS

A generic water range for the DT&E and OT&E of all-altitude short-range weapons was patterned after the SETTA range (at Eglin), the Pacific Missile Test Center (PMTC) and the Naval Air Test Center (NATC). The generic range dimensions are 200 nm x 125 nm with land bordering on two sides. This terrain is generally flat and the TSPI sensors are primarily shore-based. Weapon systems tested on the range correspond to those tested on the Land Range described in Chapter 7 with the exclusion of S-S missiles and land vehicles. As a consequence, the discussion of test article TSPI requirements given in Section 7.1 of the previous chapter is germane and is not repeated. For completeness, however, the applicable TSPI requirements for the generic Water Range have been excerpted and reproduced in Table 8-1.

8.1 GENERIC NON-GPS RANGE BASELINES

This section describes the complement of non-GPS TSPI equipments to be used on the Water Range in the near and far term. Following this discussion, a comparison of the range's capabilities and requirements is provided.

8.1.1 Instrumented Range Description

Near-Term Non-GPS Range - Because the purpose of a water range is to extend testing beyond existing land boundaries to support the evaluation of new, longer range weapons in complex M-on-N scenarios, shore- and near-shore-based sensors must be augmented by airborne instrumentation platforms to

TABLE 8-1

TSPI REQUIREMENTS*

Generic Range: All-Altitude, Short-Range Weapons Water Range

TEST PARAMETER	AIRCRAFT	DRONES	MISSILES		
			A-A	A-S	S-A
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	15-100	15-25	15-50	15-50	15-50
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-20	2	2	2	2-10
Timing (msec)	0.1	0.1	0.1	0.1	0.1
• Data Rate (#/sec)	10-50	10-50	10-100	10-100	10-100
• Post-Test Accuracy (1σ)					
Position (x,y),(z) - ft	2-15	2-15	2-15	2-15	2-15
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-10	2-10	2-10	1-10	2-10
• Scoring Accuracy (ft-1σ Circ)	---	---	1-2	1-5	1-5
• Number of Test Articles	4	6	6	6	4
• Coverage					
Altitude - kft	0-100	0-60	0-60	0-75	0-60
Distance - nm	250	50	50	50	50

*Parameter ranges, where specified, reflect differing requirements for each test phase.

overcome line-of-sight limitations (see Fig. 8.1-1). In the near term, the objective was to provide low altitude coverage for a useful portion of the water range. As a consequence, three airborne instrumentation platforms were added which could provide three-dimensional coverage, act as relays of TSPI data and augment the surveillance function. Precise aircraft position will be determined by six land-based multilateration stations (five on-shore and one near-shore). To provide support for near-shore-based, M-on-N testing when range aircraft are unavailable, ten dish tracking radars, two laser radars, eight angle-only optical trackers and two optical trackers augmented by laser rangers were furnished to complement the land-based multilateration system. Because all high accuracy scoring devices are on land, the airborne platform will have to carry additional scoring instrumentation.

Far-Term Non-GPS Range - Changes to the near-term instrumentation for the far term include both the addition of two airborne instrumentation platforms to act as multilateration and surveillance stations to increase the coverage area (see Fig. 8.1-2), and two multiple target, phased array radars to replace eight of the less efficient dish radars. (Two dish radars were left as backup.) The third major change to the far-term range is the addition of two laser radars to replace the ten labor-intensive optical trackers. The performance of both the near- and far-term ranges with respect to individual test category requirements is examined in the next subsection.

8.1.2 Non-GPS Range Capabilities

The capabilities of the non-GPS ranges are tabulated in Tables 8.1-1 through 8.1-3 for each test category. Performance parameters, with the exception of coverage, are invariant

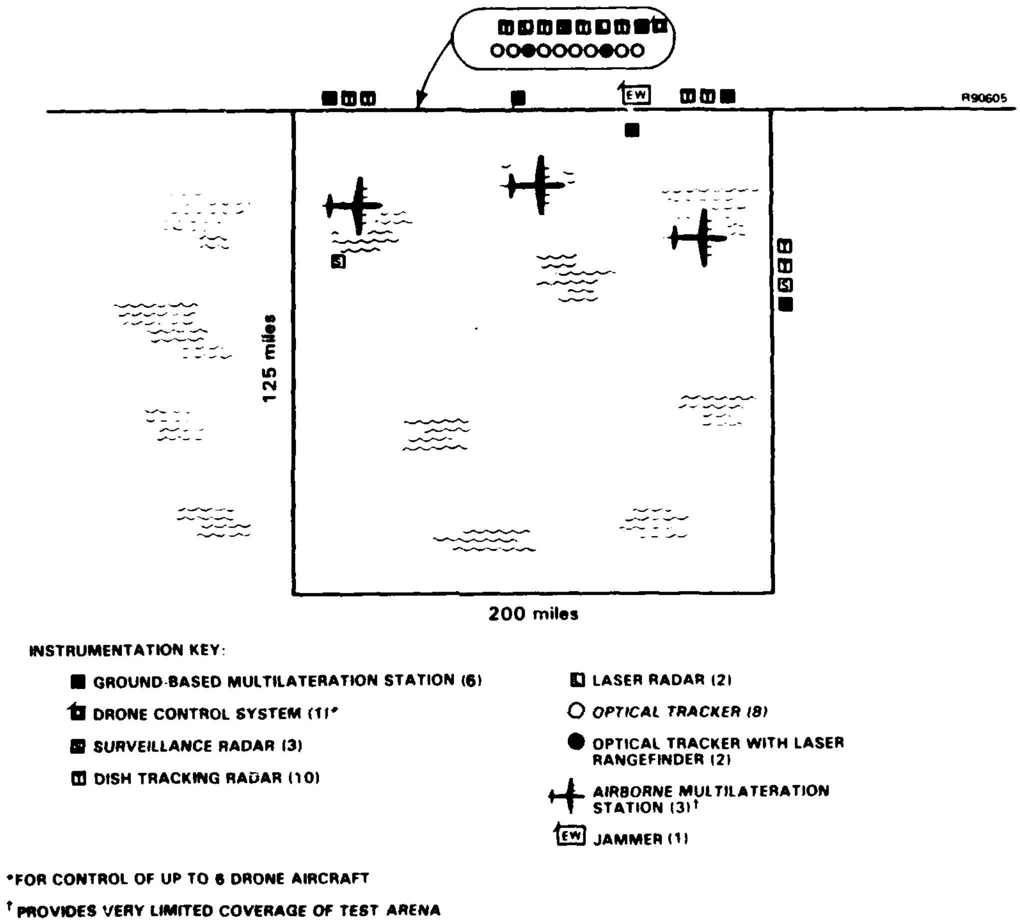


Figure 8.1-1 All-Altitude, Short-Range Weapons Generic Water Test Range: Near-Term Non-GPS Option

with time frame but do reflect the degradation imposed by the self-positioning errors of the airborne multilateration station. It should be noted that even with five airborne multilateration stations, only partial coverage of the range area is obtained although, in general, full utilization of the entire range on a simultaneous basis is unlikely.

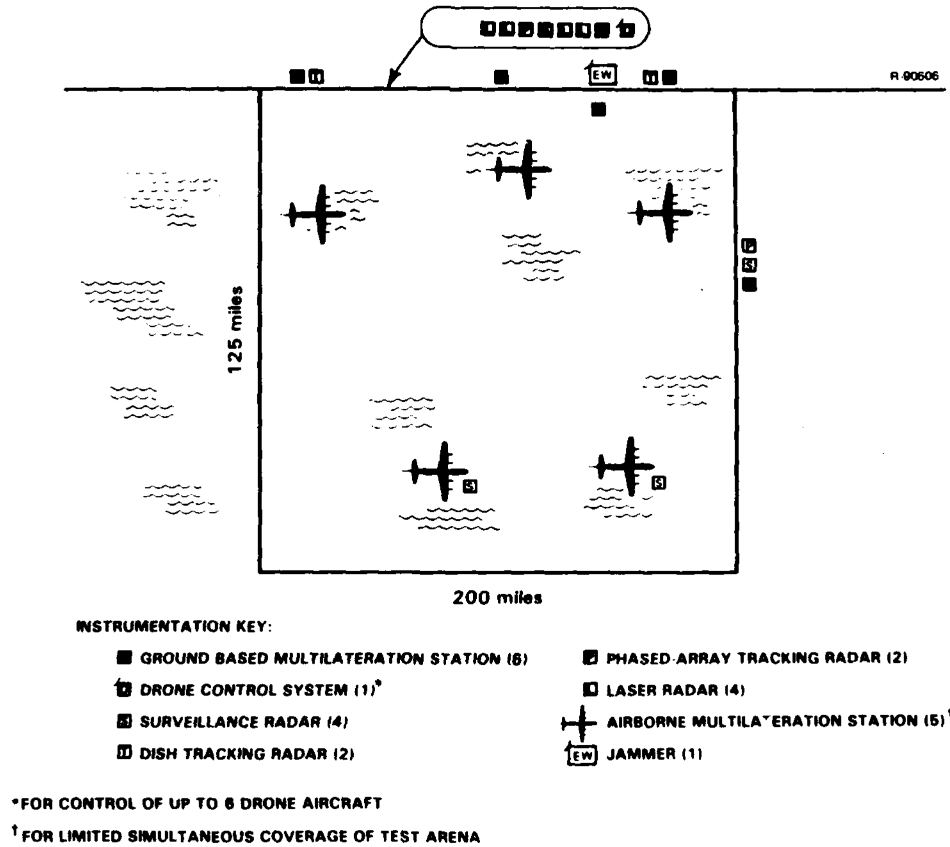


Figure 8.1-2 All-Altitude, Short-Range Weapons Generic Water Test Range: Far-Term Non-GPS Option

Estimates of the actual coverage with three, four and five airborne platforms (developed with TASC's Satellite Visibility Program Package) are summarized in Table 8.1-4. As the table indicates, the payoff in additional coverage rises slowly as each aircraft is added. The total is also practically limited by the degradation in accuracy the user is willing to suffer as the local grid is extended away from shore and by aircraft availability. The remainder of this section provides a comparison of requirements with non-GPS capabilities for each test category.

TABLE 8.1-1
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Aircraft

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	15-100	25-75,25-200	25-75,25-200
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	0.1-20	3-15, 3-50	3-15, 3-50
Timing (msec)	0.1	0.1	0.1
• Data Rate (#/sec)	10-50	10-50	10-50
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	2-15	1-5†	1-5†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	0.01-10	0.1-1†	0.1-1†
• Scoring Accuracy (ft-1σ Circ)	---	---	---
• Number of Test Articles	4	10**	10**
• Coverage			
Altitude - kft	0-100	0-100	0-100
Distance - nm	250	10-60	10-120

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Total of 10 airborne vehicles (date rate dependent).

†Near shore only. Position and velocity accuracy of 5-20 ft and 15 fps over most portions of range.

TABLE 8.1-2
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Drones

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	15-25	25-75,25-200	25-75,25-200
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2	3-15, 3-50	3-15, 3-50
Timing (msec)	0.1	0.1	0.1
• Data Rate (#/sec)	10-50	10-50	10-50
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	2-15	1-5†	1-5†
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	2-10	0.1-1†	0.1-1†
• Scoring Accuracy (ft-1σ Circ)	---	---	---
• Number of Test Articles	6	10**	10**
• Coverage			
Altitude - kft	0-60	0-60	0-60
Distance - nm	50	10-60	10-120

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Total of 10 airborne vehicles (date rate dependent).

†Near shore only. Position and velocity accuracy of 5-20 ft and 15 fps over most portions of range.

TABLE 8.1-3

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Missiles (A-A, A-S, S-A)

TEST PARAMETER	REQUIREMENTS			CAPABILITIES	
	A-A	A-S	S-A	NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	15-50	15-50	15-50	25-75,25-200	25-75,25-200
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2	2	2-10	3-15, 3-50	3-15, 3-50
Timing (msec)	0.1	0.1	0.1	0.1	0.1
• Data Rate (#/sec)	10-100	10-100	10-100	10-100	10-100
• Post-Test Accuracy (1σ)					
Position (x,y),(z) - ft	2-15	2-15	2-15	1-5†	1-5†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2-10	1-10	2-10	0.1-1†	0.1-1†
• Scoring Accuracy (ft-1σ Circ)	1-2	1-5	1-5	1	1
• Number of Test Articles	6	6	4	$\geq$10**	$\geq$10**
• Coverage					
Altitude - kft	0-60	0-75	0-60	0-75	0-75
Distance - nm	50	50	50	10-60	10-120

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Total of 10 airborne vehicle (data rate dependent).

†Near shore only. Postion and velocity accuracy of 5-20 ft and 15 fps over most portions of range.

TABLE 8.1-4

AREA COVERAGE WITH AIRBORNE MULTILATERATION PLATFORM††

(TOTAL RANGE AREA - 25,000 nm^2)

AIRBORNE PLATFORMS	AREA COVERAGE	% OF TOTAL RANGE
3	2600	10
4	4900	20
5	6200	25

††HDOP $\leq$ 3.

Aircraft - The major impact of testing aircraft on the Water Range rather than the Land Range is the degradation in post-test position and velocity incurred as the scenario moves away from the shore-based optical and laser sensors. The loss of this capability (particularly the latter) means that aircraft avionics systems cannot be evaluated over the broad range area but would be restricted to near-shore areas. A second potential problem area is the constricted instrumented arena size with respect to the 250 nm requirement, although test plans might be devised to perform critical functions in the instrumented areas.

Drones - The degradation of real-time position accuracy has important implications for drones which must be tightly controlled in formation flying. Although similar variations in non-GPS accuracy went beyond the requirements in the Land Range, they at least satisfied the requirements in good geometry tracking situations. In addition, test scenarios over the broad Water Range will reduce the possibility of meeting post-test requirements.

Missiles - The accuracy performance offered by the Water Range for missiles generally does not meet real-time performance requirements. For broad Water Range test scenarios, post-test accuracies will also be insufficient relative to requirements. Finally, for missiles, a portable scoring device must be made available to the airborne platform to support this function.

8.2 GPS SCENARIO DEVELOPMENT

The near- and far-term GPS ranges are defined in this section along with suitable configurations for developing a

GPS capability. This is followed by a GPS requirements vs capabilities comparison and a discussion of the tradeoffs to be considered when implementing the airborne inverted range.

8.2.1 Instrumented GPS Range Description

The near-term GPS range (shown in Fig. 8.2-1) evolved by replacing the land-based and airborne multilateration stations with an equal number of land-based and airborne pseudolites. As a consequence, essentially equivalent coverage was obtained. In addition to the pseudolites, GPS-specific equipment such as differential stations and airborne translator signal receivers were furnished to support GPS-based TSPI.

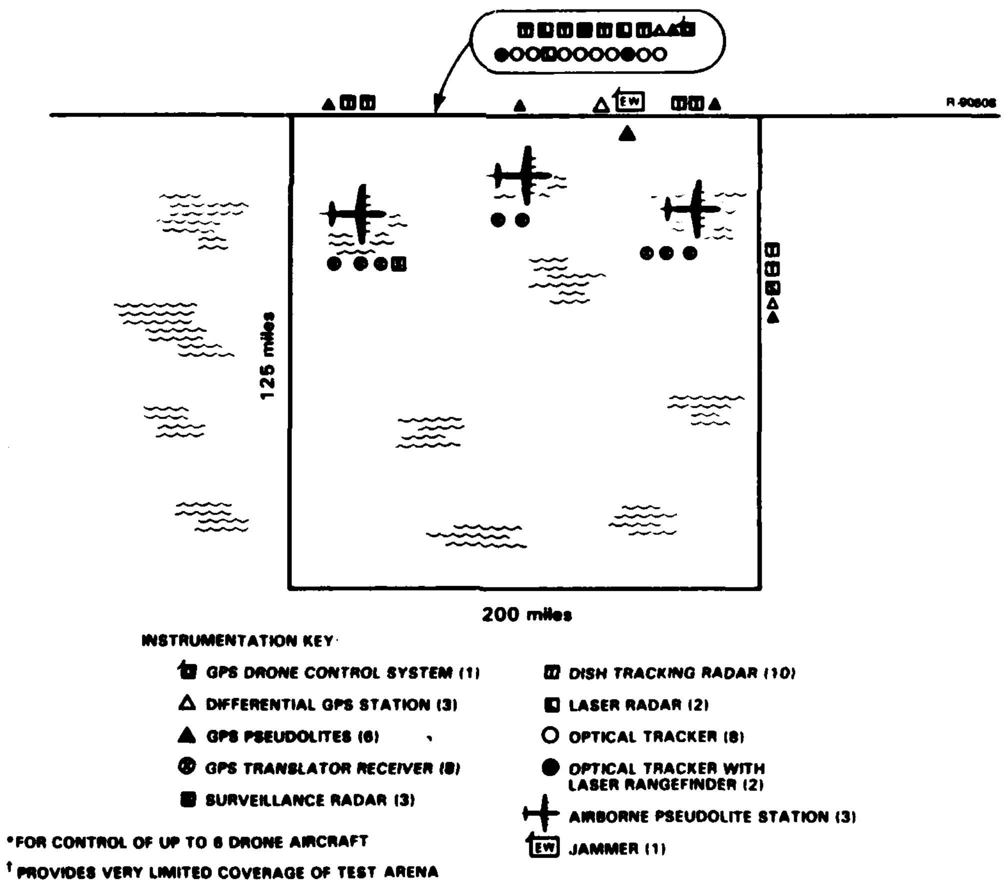


Figure 8.2-1 All-Altitude, Short-Range Weapons Generic Water Test Range: Near-Term GPS Option

In the far term, the three airborne pseudolite aircraft were replaced by two range aircraft serving as relays and surveillance platforms (see Fig. 8.2-2). In addition four of the land-based pseudolites were removed, leaving two others to act as EW adjuncts and GDOP enhancers. Finally, all optical trackers and six dish radars were eliminated with some of the former's functions supplemented by two laser radars as was done with the non-GPS range counterpart. Table 8.2-1 provides a comparative summary of the near- and far-term instrumentation options.

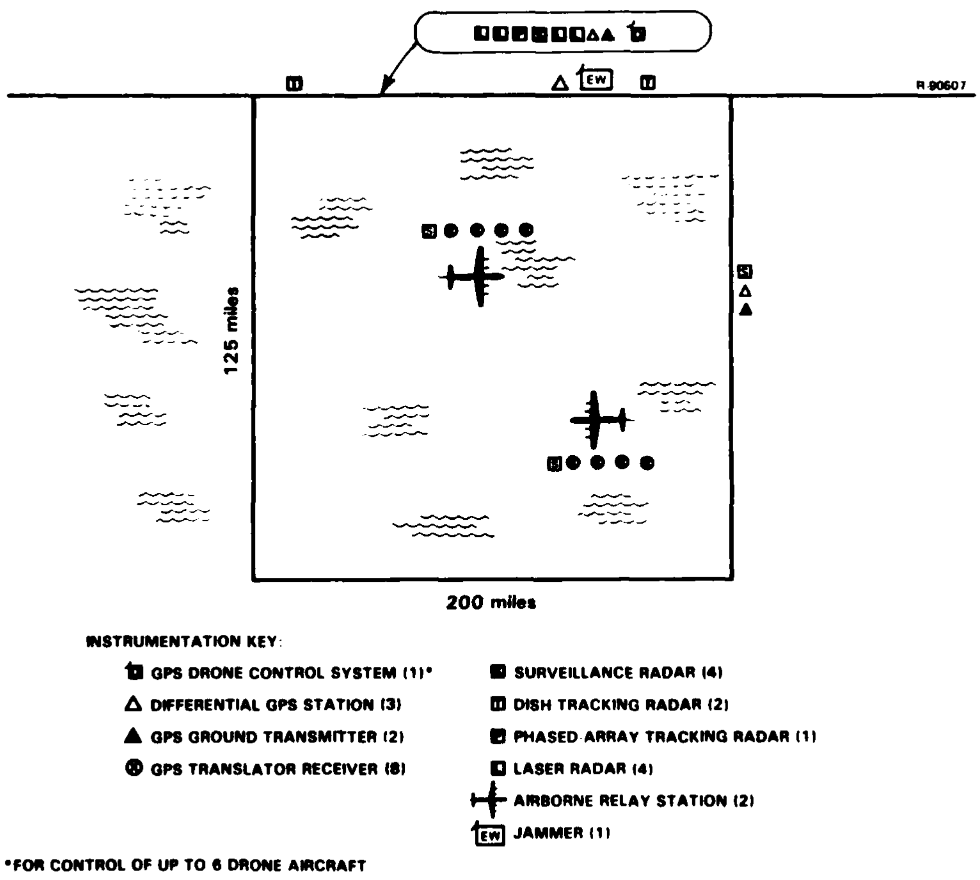


Figure 8.2-2 All-Altitude, Short-Range Weapons Generic Water Test Range: Far-Term GPS Option

TABLE 8.2-1

INSTRUMENTATION OPTIONS COMPARISON
SHORT-RANGE WEAPONS WATER RANGE

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station			GPS Equipment		
Land-Based	---	6	Land-Based Pseudolite	6	---
Airborne	---	3	Airborne Pseudolite	3	---
Drone Control Station	1	1	Differential Station	3	---
Tracking Radar			Translator Receiver	8	---
Dish	10	10	Geoceiver	1	---
Laser	2	2	Timing Receiver	1	---
Optical Tracker			Surveillance Radar		
With Laser Rangefinder	2	2	Land-Based	2	2
Without Laser Rangefinder	8	8	Airborne	1	1
			Test Article Equipment	Yes	Yes
			Support Aircraft	3	3

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station			GPS Equipment		
Land-Based	---	6	Land-Based Pseudolite	2†	---
Airborne	---	5	Differential Station	3	---
Drone Control Station	1	1	Translator Receiver	8	---
Tracking Radar			Geoceiver	1	---
Dish	2	2	Timing Receiver	1	---
Phased Array	1	2	Surveillance Radar		
Laser	4	4	Land-Based	2	2
			Airborne	2	2
			Test Article Equipment	Yes	Yes
			Support Aircraft	2	5

8.2.2 GPS Range Capabilities

Three GPS configurations for the five categories of weapon systems were chosen in accordance with the requirements

and volume constraints described in Section 7.3.2 of the previous chapter. In these configurations (see Section 3.4), the dotted box labelled "Monitor and Relay Station or Control Center" represents the airborne instrumentation platform. The configurations shown are identified in Table 8.2-2 through 8.2-4 along with the capabilities of each as modified to reflect the use of the airborne inverted range in the near term. The remainder of this section provides comparison of requirements and capabilities for each test category.

Aircraft - One of the ramifications of using a moving baseline, inverted range to track aircraft can be appreciated by comparing the near- and far-term GPS velocity accuracies and the requirements for avionics testing (0.1 and 0.01 fps). Where nominal far-term GPS accuracies are adequate for avionics evaluation, the degraded near-term accuracies (although still useful) do not meet the requirements. Another area where degraded performance in the near term is significant is post-test position accuracy, for which the available performance is marginal, even with a multi-channel P-code receiver. With the C/A-code translator, the near term degradation in real-time and post-test position exacerbates an already marginal tracking situation while velocity still remains useful. Finally, it should be noted that coverage requirements for aircraft can never be met in the near term.

Drones - In drone applications, the impact of degraded real-time position accuracy is an important factor since these vehicles are generally flown in formation. Relative to meeting real-time requirements, however, C/A-code is inherently too coarse. Nevertheless, for larger vehicles where multi-channel P-code receivers can fit volume constraints, the near-term degradation in performance would still permit most requirements to be met.

TABLE 8.2-2
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Aircraft

TSPI Configuration Number: 1. (Onboard or Pod P-Code Receiver - Differential Mode)
2. (Pod Plus Operational P-Code Receiver - Differential Mode)
3. (Onboard or Pod C/A-Code Translator - Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY			
		NEAR TERM (RECEIVER)	FAR TERM (RECEIVER)	NEAR TERM (TRANSLATOR)	FAR TERM (TRANSLATOR)
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	15-100	15,19	7,12	47,58	25,41
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-20	0.11,0.21†	0.06,0.11†	0.11,0.21†	0.06,0.11†
Timing (msec)	0.1	0.0001	0.0001	0.0001	0.0001
• Data Rate (#/sec)	10-50	10-50†	10-50†	10-50†	10-50†
• Post-Test Accuracy (1σ)					
Position (x,y),(z) - ft	2-15	8,10	2,4	15,19	6,10
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.01-10	0.04,0.06	0.02,0.03	0.04,0.06	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	---	---	---	---	---
• Number of Test Articles	4	Unlimited**	Unlimited**	>4	>4
• Coverage					
Altitude - kft	0-100	0-100††	0-100+	0-100††	0-100+
Distance - nm	250	10-60	250+	10-60	250+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Potentially limited by telemetry capacity only.

†With IMU.

††Two or more satellites available 12-17 hrs. per day for z data.

<u>Missiles</u> - The application of C/A-code translator to missiles in the near term results in position accuracies which are too coarse for the tracking requirements. In the far term, however, real-time accuracy is adequate and post-test accuracy marginal-to-good. For far-term applications where all-digital P-code receivers may fit volume constraints, all requirements would be met.

TABLE 8.2-3

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Drones

TSPI Configuration Number: 3. (Onboard C/A-Code Translator-Differential Mode)
1. (Onboard P-Code Receiver-Differential Mode)

TEST PARAMETERS	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM (TRANSLATOR)	FAR TERM (RECEIVER)
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	15-25	47,58	7,12
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2	0.11,0.21†	0.06,0.11†
Timing(msec)	0.1	0.0001	0.0001
• Data Rate (#/sec)	10-50	20-50†	10-50†
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	2-15	15,19	2,4
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	2-10	0.04,0.06	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	---	---	---
• Number of Test Articles	6	6	6
• Coverage			
Altitude	0-60	0-60**	0-60+
Distance - nm	50	10-60	50+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Two or more satellites available 12-17 hrs per day for "z" data.

†With IMU.

TABLE 8.2-4

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: All-Altidude, Short-Range Weapons Water Range (DT&E, OT&E)

Generic Test Category: Missiles (A-A, A-S, S-A)

TSPI Configuration Number: 4. (Onboard C/A-Code Translator - Differential Mode) - Near Term, Far Term
1. (Onboard P-Code Receiver - Differential Mode) - Far Term Only

TEST PARAMETER	TSPI REQUIREMENTS			GPS TSPI CAPABILITY		
	A-A	A-S	S-A	NEAR TERM (TRANSLATOR)	FAR TERM (TRANSLATOR)	NEAR TERM (RECEIVER)
• Real-Time Accuracy (1σ)						
Position (x,y),(z) - ft	15-50	15-50	15-50	47,58	25,41	7,12
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	2	2	2-10	0.11,0.21	0.06,0.11†	0.06,0.11†
Timing (msec)	0.1	0.1	0.1	0.0001	0.0001	0.0001
• Data Rate (#/sec)	10-100	10-100	10-100	10-50†	10-50†	10-50†
• Post-Test Accuracy (1σ)						
Position (x,y),(z) - ft	2-15	2-15	2-15	15,19	6,10	2,4
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	2-10	2-10	2-10	0.04,0.06	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	1-2	1-5	1-5	---	---	5
• Number of Test Articles	6	6	4	6	6	Unlimited**
• Coverage						
Altitude - kft	0-60	0-75	0-60	0-60††	0-75+	0-75+
Distance - nm	50	50	50	10-60	50+	50+

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Two or more satellites available 12-17 hrs. per day for z data.

†With IMU.

8.2.3 GPS Application Issues

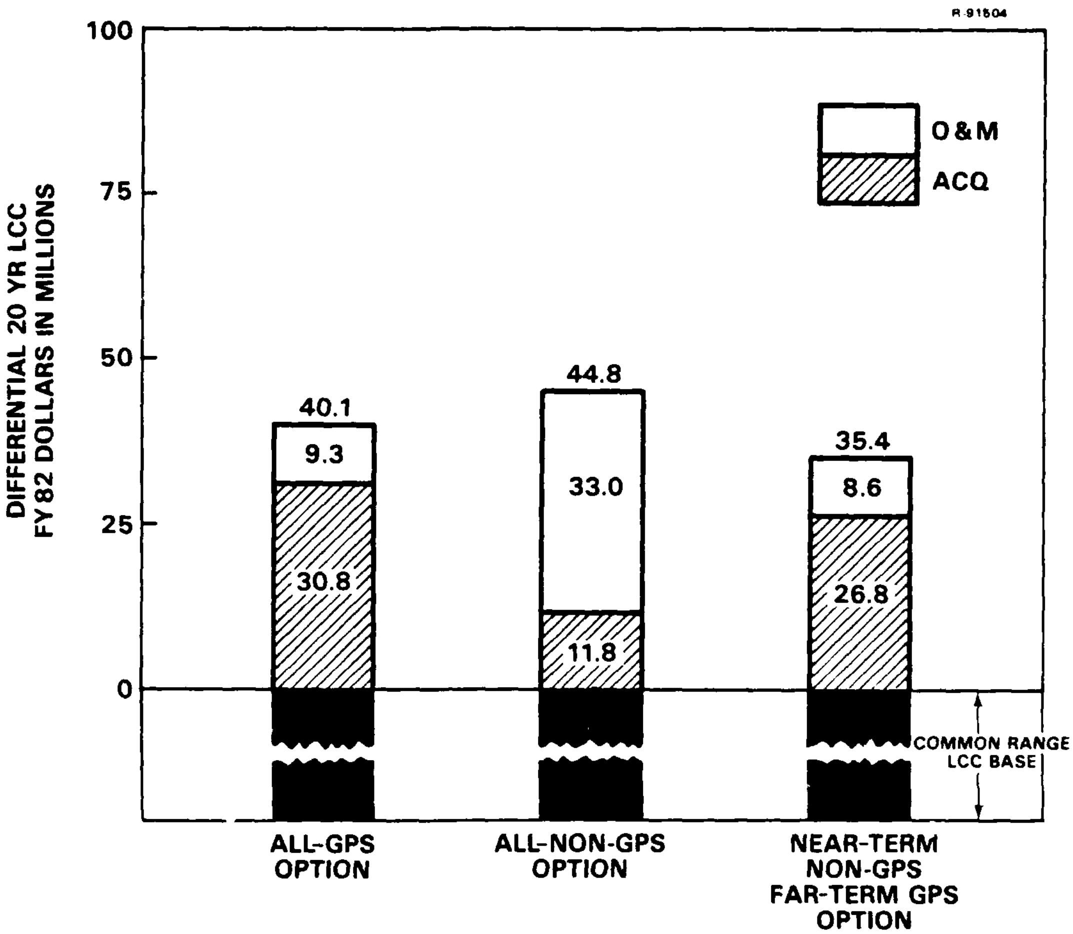
A number of different implementations of the near-term GPS range off-shore extension were contemplated because of the likelihood that a GPS receiver could be captured or have its performance degraded by a co-located airborne pseudolite (see Section 3.1). Possible implementations included the use of airborne relays and translators, in addition to pseudolites, to circumvent this potential problem. One possible approach is described below.

Because the airborne pseudolites are part of a moving baseline system, the position of the range aircraft must be precisely known if accurate, absolute tracking data is to be derived. An onboard receiver used to collect signals from GPS ground transmitters and available satellites could be used to continuously establish the position of the aircraft if it were not for the capture/degradation problem. One way to avoid this problem is to blink the pseudolite with an on-sequence lasting a few minutes (during which time the onboard receiver is blanked) and an off-sequence lasting for a few seconds. In order to maintain track of the range aircraft's position during the on-sequence, IMU aiding is required, which not only acts as a data gap filler but can help the onboard receiver quickly reacquire the GPS signals. (Reacquisition will also be aided by the fact that the receiver will be operating in a relatively benign dynamic environment.)

The advantages of this approach are that standard equipment (L-band transmitters and receivers) may be used and low dynamic players will be only slightly affected if the broadcast sequences are chosen judiciously. Potential disadvantages exist in terms of tracking performance for high dynamic uses where IMU aiding is not available. Obviously then, the key to the viability of this approach is the development of an optimum duty cycle strategy.

8.3 LIFE-CYCLE COST COMPARISON

For the Short-Range Weapons generic Water Range, the differential 20-year life-cycle cost comparison between the all-GPS option versus the all-non-GPS option and the near-term non-GPS/far-term GPS option (mixed option) is shown in Fig. 8.3-1. The major contributors to cost in the all-GPS option are the development, acquisition and O&M of GPS range equipments which



- Federated Drone Control/Multilateration
- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based On Consolidated Buy

Figure 8.3-1 All-Altitude, Short-Range Weapons Water Range LCC Comparison

include inverted range items as well as short-range translators and multi-channel receivers for the test articles. The cost and user equipment buy numbers were extracted from the tables presented in Section 4.2 and Table 8.2-1.

The all-non-GPS option costs are driven by the acquisition of user equipment transponders, the acquisition and O&M

of a single-faced, phased array radar in the far term, and the continued use of three support aircraft in the far term. The support aircraft are unique to this differential analysis and were costed out assuming flying time of 3 hours per day, 5 days per week. Costs were calculated by using the cost per flying hour of $362 for a C-7 aircraft, as contained in Ref. 14, yielding an operating cost per aircraft, of approximately $280K. The costs for the mixed option reflect lower acquisition and O&M costs, because GPS equipments are not purchased and maintained until the far term.

As shown in Fig. 8.3-1, the differential LCC analysis indicated a small but measurable cost advantage to the GPS options over the non-GPS options. However, the error band around the ROM cost estimates (±25%) would suggest that the three options are essentially equal in terms of cost and that the decision to commit to GPS should be based on criteria other than cost. Sensitivity analyses performed on translator and receiver quantities and unit costs, and on phased array radar unit costs favored GPS-based options in some cases and non-GPS-based solutions in others, with no clear-cut cost winner.

8.4 GPS RANGE EFFECTIVENESS EVALUATION

Although the Short-Range Weapons Water Range supported testing of most of the same test categories as did the Short-Range Weapons Land Range, the effectiveness analysis results varied in several respects due to the differences in the range characteristics. These differences are illustrated in Table 8.4-1 and 8.4-2 (the latter being a duplicate of Table 7.5-2). Under "Drivers", low altitude coverage and data rate exhibit differences in ratings between the two ranges. For example, while only GPS can offer low altitude coverage on the Land Range in the near term (for most of the time), both GPS and the non-GPS

TABLE 8.4-1

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

(WATER RANGE)

Generic Range: All-Altitude, Short-Range Weapons Water Range (DT&E, OT&E)

Test Category: Aircraft, Drones, Missiles (A-A, A-S, S-A, S-S),

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE* NEAR TERM	GPS RELATIVE ADVANTAGE* FAR TERM	PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
DRIVERS:				
• Real-Time Accuracy	⊞	⊞	Aircraft, Drones (F)	Better Velocity
• Post-Test Accuracy	⊞	⊞	Aircraft	
• Broad Coverage	0	+	All	Good GDOP
• Low Altitude Coverage	0	0		
• Number of Players	0	0		
• Data Rate	0, -	0	Drone, Missile (W/O IMU)	20-30 Hz W/O IMU
CONSIDERATIONS:				
• Integration	0	+	All	Fewer Ground Stations
• Technical Risk	⊟	⊟	Aircraft, Missile	Antenna Blockage; Translator Issues
• Growth Potential	0	+	Drones, Missiles	Tighter Formations, Longer Range
• Standardization	0	+	Aircraft	Single TSPI Source
• Portability	0	0		
• Availability	0	⊞	All	Minimizes Air, Ground Support
• Data Timeliness	0	0		
GPS APPLICABILITY	MOD	HIGH	Better Accuracy, Fewer Support Systems in Far Term	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

options on the water range can accomodate this requirement in both the near- and far-term. However, broad coverage for both ranges can only be accomplished with GPS in the far term. For the data rate requirement, differences in the far term ratings are due to limitations imposed by the airborne multilateration system, which cannot support both the high data rate and number of players simultaneously. By contrast, the Land Range has a number of ground systems to augment its non-GPS multilateration system for high data rate tracking.

Under "Considerations", differences exist not so much in the ratings but in their rationale. For example, on the Water Range, a significant integration issue is the number of

TABLE 8.4-2

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

(LAND RANGE)

Generic Range: All-Altitude, Short-Range Weapons Land Range (DT&E, OT&E)

Test Category: Aircraft, Drones, Missiles (A-A, A-S, S-A, S-S), Land Vehicles

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
DRIVERS:				
• Real-Time Accuracy	$\boxed{+}$	$\boxed{+}$	Aircraft, Drones (F)	Better Velocity
• Post-Test Accuracy	$\boxed{+}$	$\boxed{+}$	Aircraft	
• Broad Coverage	0	+	Aircraft, Drones, Missiles	Data Link LOS Restrictions Only
• Low Altitude Coverage	+	+	Aircraft, Drones, Missiles	
• Number of Players	0, -	0, -	A-S WASP Missile	Possible Translator BW Limits
• Data Rate	0, -	0, -	Drone, Missile (W/O IMU)	20-30 Hz W/O IMU
CONSIDERATIONS:				
• Integration	0	+	Aircraft, Drones	No "Z" Aiding
• Technical Risk	$\boxed{-}$	$\boxed{-}$	Aircraft, Missile, Drones(F)	Antenna Blockage; Translator Issues
• Growth Potential	0	+	Drones	Precise Formations
• Standardization	0	+	Aircraft, Drones, Missiles	Fewer TSPI Sources
• Portability	0	0		
• Availability	0	+	Aircraft, Drones, Missiles	Less Reliance on Older Equipment
• Data Timeliness	+	0	Aircraft	Labor Intensive Optics Avoided
GPS APPLICABILITY	HIGH	HIGH	Coverage and Accuracy in Far Term	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

ground stations which no longer have to be operated with the full GPS constellation, while "z" aiding is the corresponding issue for the Land Range. A second, and perhaps the most important "Consideration" on the Water Range, is the reduced dependence on aircraft availability since GPS needs fewer aircraft to cover the data collection, relay and range safety functions. On the Land Range, however, availability is improved only because of lower reliance on older equipments.

9. SEA-BASED WEAPONS, FIXED-BASELINE GENERIC RANGE ANALYSIS

The fixed-baseline generic range used for sea-based weapons consists of a water area measuring 50 x 100 nm bounded by a generally flat frontal shore area on one side and a mountainous region on the left. It is patterned primarily after the following ranges: 1) Pacific Missile Test Center (PMTC), 2) Pacific Missile Range Facility (PMRF), 3) Fallon, 4) Virginia Capes (VACAPES), and 5) Atlantic Fleet Weapon Training Facility (AFWTF). The range must support two distinct types of operations, i.e., training and operational test and evaluation (OT&E). The primary function of the training range instrumentation is to support the evaluation of crew effectiveness, whereas the primary function of OT&E is to support the evaluation of the weapons systems.

Crew evaluation training consists, in part, of scoring practice bombs, rockets and gun projectiles and has no other TSPI requirements imposed. Missiles are rarely fired because of cost. When missles are fired, however, missile parameter telemetry is sufficient to support crew evaluation, so TSPI information is not required except for range safety. Therefore the only vehicles that require TSPI information for crew training are aircraft, ships and drones. Weapon system test and evaluation does, however, require TSPI data on all the vehicles involved; i.e., ships, aircraft, drones and missiles.

9.1 TSPI REQUIREMENTS ASSESSMENT

TSPI requirements, summarized in Table 9.1-1, were developed in part from the accuracy requirements specified for the pattern ranges. However, in some cases, different ranges specified different TSPI requirements for the same test vehicle. Furthermore, some of the accuracies given were based on a best estimate using multiple measurement sensors, which is not apropos for the generic range where many participants are assumed. As a result, the table shows a set of requirements which are developed from a combination of data base inputs along with engineering judgement. The requirements for each test article will now be discussed in turn.

Aircraft - The real-time position accuracy requirement is relatively stringent because real-time information is needed to assess performance in air combat maneuvering (ACM) training involving multiple participants. A 10 ft position and 2 fps velocity accuracy is necessary for scoring purposes during no-drop bomb (or mine) runs. Attitude information is also required for scoring purposes; i.e., simulated missile firings and bomb releases.

Ships - The real-time accuracy shown is useful for range control purposes. The relatively coarse precision is related to its function of tracking intruder ships which are not part of the exercise. Post-test accuracy requirements for participants is better than 100 feet. For some exercises, the number of surface ships can be as high as 25.

Missiles - All three types of missiles using the range (air-to-air, air-to-surface, and surface-to-air) are shown in this requirements table. The post-test velocity accuracy requirement has been specified by the pattern ranges to be on

TABLE 9.1-1

TSPI REQUIREMENTS*

Generic Range: Sea-Based Weapons, Fixed-Baseline

TEST PARAMETER	AIRCRAFT	SHIPS	MISSILES A-A, A-S, S-A	DRONES
• Real-Time Accuracy (1σ)				
Position (x,y),(z) - ft	25	<3000	---	200
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	15	---	---	---
Timing (msec)	---	---	---	---
• Data Rate (#/sec)	5	0.1	10	10
• Post-Test Accuracy (1σ)				
Position (x,y),(z) - ft	10-25	<100	50	200
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	(2-15)†	25	0.1-20	---
• Scoring Accuracy (ft-1σ Circ)	---	---	---	---
• Number of Test Articles	SVT-16, POS-20	25	2	6
• Coverage				
Altitude - kft	0.1-60	0	0-60	0-60
Distance - nm	50 x 100	50 x 100	50 x 100	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Attitude <2 deg, Acceleration <0.5 g, Roll Rate <5 deg/sec.

the order of 10-20 fps. For most missiles, this accuracy is sufficient. However, for those missiles which have an inertial midcourse capability, a velocity measurement of 0.1 fps is required for OT&E. This measurement accuracy is roughly 20% of the velocity error expected from an inertial system on board a missile.

Drones - The pattern range documentation provided no specific TSPI accuracy requirements for drones. They do say, however, that the requirements are met by existing drone tracking systems capabilities. These capabilities are specified in

terms of range and angle accuracies rather than position accuracies which translate into a position accuracy equal to the range accuracy of 200 feet. This accuracy is required over the extent of the generic range from sea level to an altitude of one hundred thousand feet and is driven by the need for formation control.

9.2 GENERIC NON-GPS RANGE BASELINES

This section describes the instrumentation resources available on the near- and far-term non-GPS generic range. It also provides a comparison of the non-GPS range's capabilities and relate them to the TSPI requirements.

9.2.1 Instrumented Range Description

The near- and far-term non-GPS ranges are illustrated in Figs. 9.2-1 and 9.2-2 respectively. The shoreline in front of the ships contains a multilateration system for ACM training and simulated ordnance firings/launches. Also shown are a ship hulk and a small island, which are both uninstrumented. These areas are used for strafing and bombing runs. Also shown in the figure on the left side of the range is a complement of instrumentation residing on high ground. This equipment is used for air and sea exercises that occur well away from land. The island situated below the hulk provides a drone control station. It also includes a tracking radar and telemetry receivers as instrumentation resources.

Near-Term Non-GPS Range - There are seven multilateration stations used to collect TSPI data during airborne exercises. They are situated to provide a coverage area of approximately 750 square miles. Two of the stations are positioned

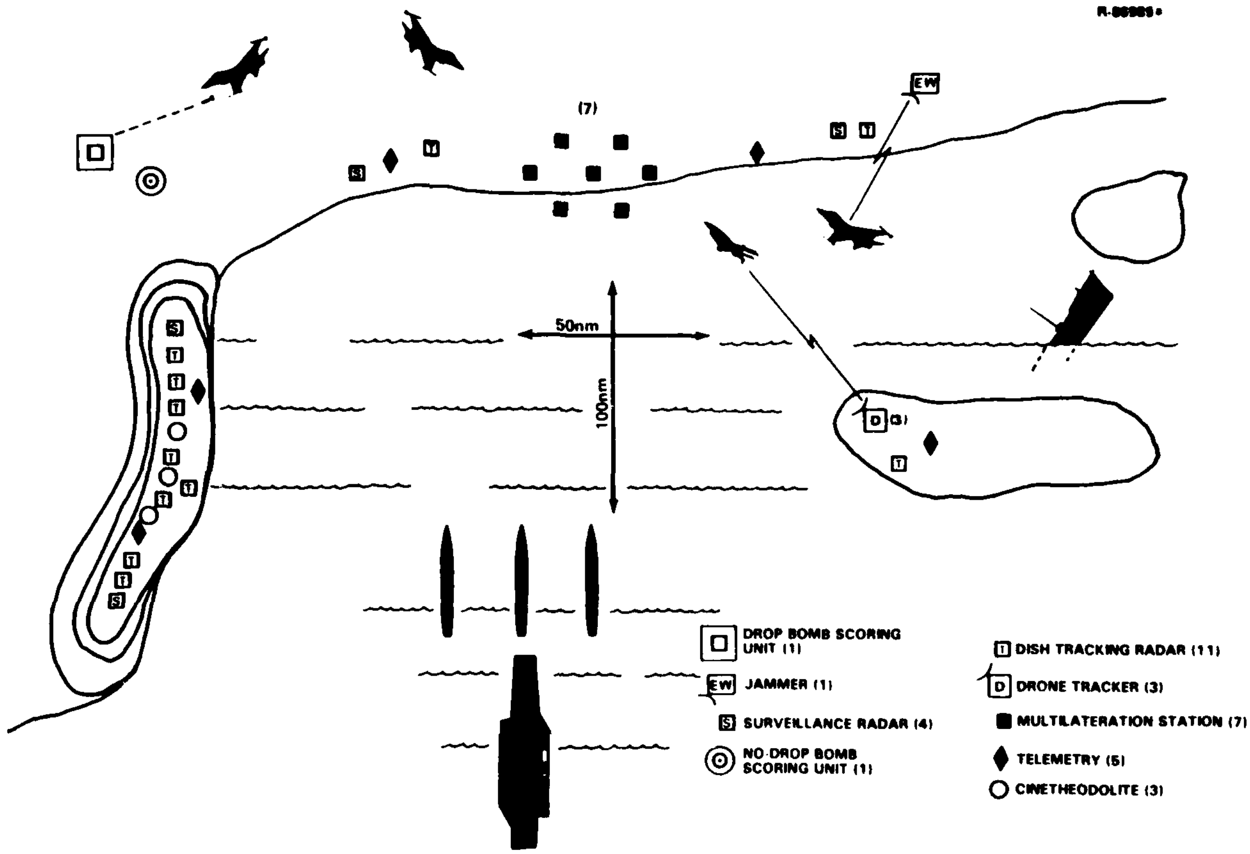


Figure 9.2-1 Sea-Based Weapons Generic Training Range (Fixed Baseline): Near-Term Non-GPS Option

several miles out to sea to provide limited coverage away from shore. The multilateration system is capable of supporting 12 high performance and 20 medium performance participants. For ship-based exercises, a complement of shore-based tracking radars is used to provide TSPI information. These instruments are used because of their narrow beamwidths, which minimize the effects of multipath on accuracy performance for both ships and low flying aircraft. Optics are also used in conjunction with the radars, but are limited to scenarios where timely TSPI data is not needed due to the long delay used to process the film. The drone control system is capable of range/angle/angle tracking of 3 targets.

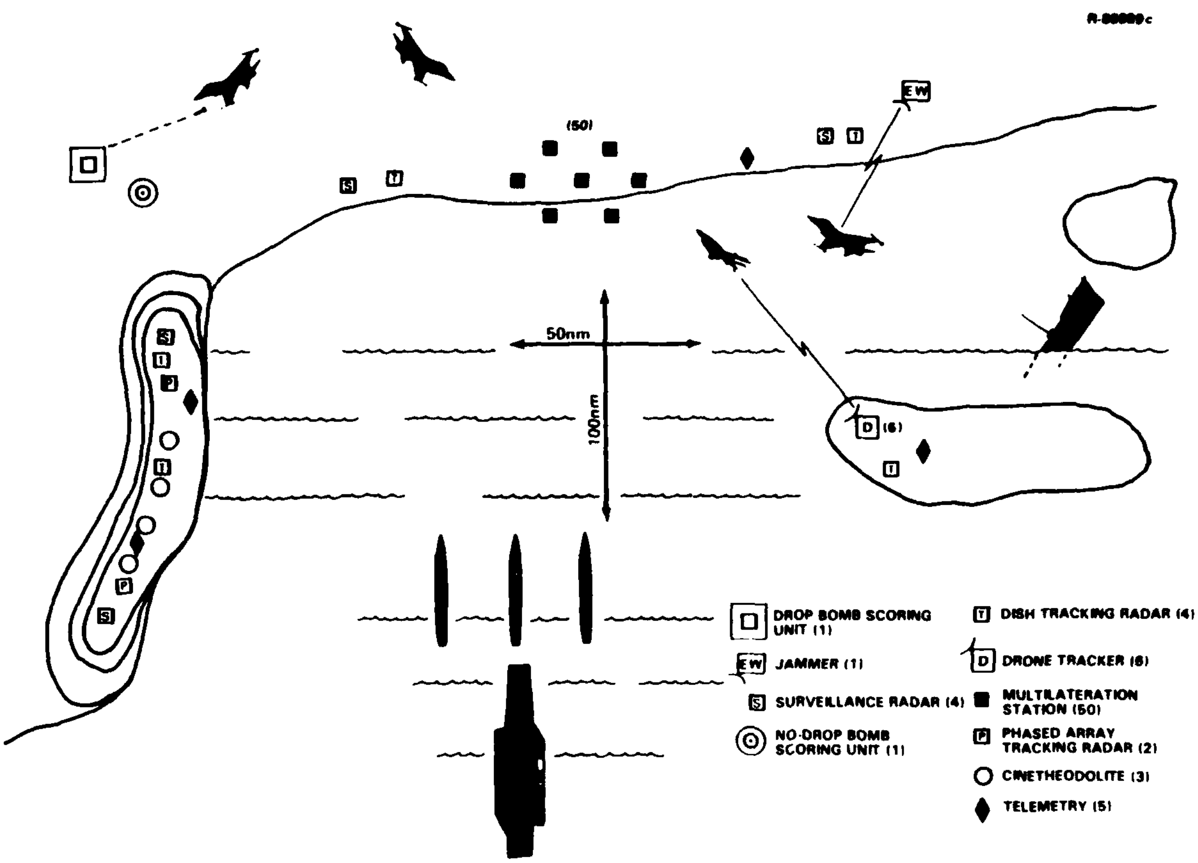


Figure 9.2-2 Sea-Based Weapons Generic Training Range (Fixed Baseline): Far-Term Non-GPS Option

Far-Term Non-GPS Range - The far-term non-GPS range is similar to the near term range with the exception of three significant changes to the instrumentation complement. First, the drone control capability has been expanded to accommodate six simultaneous drone flights. Second, the multilateration system coverage area requirements have been expanded from 900 to 5000 square miles resulting in the need for 50 ground stations. Third, the number of tracking radars has been reduced by replacing seven of them with multiple object tracking, phased array radars.

9.2.2 Non-GPS Range Capabilities

TSPI capabilities of the near- and far-term ranges are given in Table 9.2-1, 9.2-2 and 9.2-3. The first table shows the overall TSPI accuracy capabilities required for training over land, as they relate to aircraft and missiles while the second table shows the TSPI accuracy capabilities required for training and OT&E exercises at sea. This break out of capabilities is necessary because two distinct types of TSPI measurement systems are used; i.e., a multilateration system over land, and tracking radars at sea. The third table shows drone control capabilities which are obtained from a range/angle/angle tracking system and are applicable to both over-land and at-sea exercises. It should be noted that the near- and far-term accuracy capabilities do not change. Only the amount of coverage, and the number of allowable participants in an exercise.

Over-Land Capabilities (Table 9.2-1) - The over-land TSPI capabilities shown for aircraft and missiles result from the use of a multilateration measurement system. They meet the real-time capabilities necessary for scoring simulated firings by the aircraft and the range safety requirements for missiles. The post-test requirements are generally met by the multilateration system with an exception involving scoring for no-drop bombing exercises. These position and velocity measurement requirements are more stringent because they are used to predict the impact point of the simulated bomb releases. Although a no-drop bomb scoring unit is a range resource, its 200 ft accuracy capability does not meet the range needs.

The number of participants required for over-land exercises totals fifty. Thirty of the participants require state vector tracking (SVT) which includes not only TSPI measurements, but also attitude measurements, which are obtained

TABLE 9.2-1
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline (Training)

Generic Test Category: Aircraft, Missiles (Over Land)

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	25	25	25
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	15	15	15
Timing (msec)	--	--	--
• Data Rate (#/sec)	5	5	5
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10†-50	25	25
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	0.1-15	15	15
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	SVT-16, POS-20	SVT-8 POS-12	SVT-16 POS-20
• Coverage			
Altitude - kft	0.1-60	0.2-60	0.2-60
Distance - nm	75 x 75	30 x 30	75 x 75

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†Requirement set by no-drop bomb scoring.

from an inertial measurement unit (IMU) carried in a test pod mounted external to the aircraft. Neither the near- nor the far-term range capability meets the number of participants requirement.

The area coverage requirement is satisfied by the far-term capabilities by adding a significant number of ground

TABLE 9.2-2
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline (Training, OT&E)

Generic Test Category: Ships, Aircraft, Missiles (At Sea)

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	25-3000	30-75, 75-500	30-75, 75-500
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	15	6-15, 15-100	6-15, 15-100
Timing (msec)	--	--	--
• Data Rate (#/sec)	0.1-10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10-100	30-75, 75-500	30-75, 75-500
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-20	6-15, 15-100	6-15, 15-100
• Scoring Accuracy (ft-1σ Circ)			
• Number of Test Articles	50	<50	<50
• Coverage			
Altitude - kft	0-60	0.2-60	0.2-60
Distance - nm	50 x 100	30 x 30	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

stations. However, the minimum altitude requirement is not satisfied because of the deficiency inherent in any ground-based system which requires line-of-sight measurements. The range multilateration system requires that the participant

TABLE 9.2-3

REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline (Training, OT&E)

Generic Test Category: Drones (Over Land, At Sea)

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY**	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	200	200 (0.06°,0.11°)	200 (0.06°,0.11°)
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--	--	--
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	200†	200 (0.06°,0.11°)	200 (0.06°,0.11°)
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--	--	--
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	6	3	6
• Coverage			
Altitude - kft	0-60	0.2-60	0.1-60
Distance - nm	50 x 100	50 x 100	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Position is specified in range, and angle (azimuth, elevation).

†Engineering judgment.

vehicle be within line-of-sight of at least three ground stations. Earth curvature, and more importantly, terrain masking determine the minimum altitude at which the vehicle can operate.

At-Sea Capabilities (Table 9.2-2) - On the Sea-Based Weapons Fixed-Baseline Range, TSPI measurements are made by tracking radars that are mounted on high ground overlooking the water. Because of the range/angle/angle measurement characteristic of radars, the accuracy capability degrades linearly (in two dimensions) as a function of range. At low altitudes, where triangulation measurements can be obtained from additional resources (radar and optics), the "z" measurement capability suffers due to poor GDOP in addition to error contributors such as tropospheric refraction and multipath.

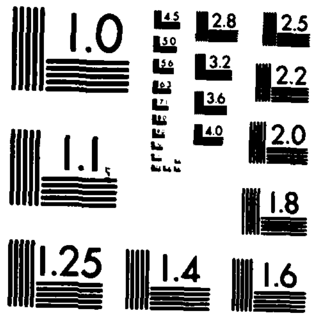
As can be seen in Table 9.2-2, the post-test accuracy requirements are generally not met in either position or velocity. Furthermore, the number of available resources is not sufficient to provide coverage for fifty players, even in the far term when multiple object, phased array tracking radars will be deployed. Although the area coverage requirement is met in the far term, minimum altitude coverage is not met because of the line-of-sight constraint at long ranges.

Drone Capabilities (Table 9.2-3) - The real-time drone measurement accuracy capability of the non-GPS range is important because it impacts how well the drone flight path can be controlled. This is especially significant when a tight formation of drones is used to evaluate missile guidance system capability during tests against multiple targets. The range/angle/angle measurement technque used for drones meets time position accuracy requirements less than 50 miles from the control station in both the near- and far-terms. An examination of other TSPI performance parameter shows that the number of drones which must be controlled can only be satisfied in the far-term. In addition, the minimum altitude requirement cannot be met because of the line-of-sight nature of the system.

AD-A128 953 GPS (GLOBAL POSITIONING SYSTEM) RANGE APPLICATIONS STUDY(U) ANALYTIC SCIENCES CORP READING MA R G BALDWIN ET AL. 31 DEC 82 TASC-TR-4175-1

3/4

UNCLASSIFIED WSMC-TR-82-3 F04703-82-C-0220 F/G 17/7 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

It is apparent from the above discussion that resources constrained to land do not provide an adequate measurement capability for at-sea exercises even when multiple instruments are employed to obtain TSPI measurements on a participant.

9.3 GPS SCENARIO DEVELOPMENT

GPS baseline ranges are described in this section in a similar manner as that used in Section 9.2 for the non-GPS ranges. Two additional aspects are also covered: a comparison of GPS vs non-GPS range resources, and the issues associated with implementing a GPS-based range.

9.3.1 Instrumented GPS Range Description

The near- and far-term generic ranges employing GPS instrumentation for obtaining TSPI measurements are shown in Figs. 9.3-1 and 9.3-2, respectively. The basic features of the ranges described in Section 9.2 are still applicable. Only the instrumentation resources have changed.

Near-Term GPS Range - The near-term GPS range looks quite similar to its non-GPS counterpart, with the most significant change being that the multilateration system has been replaced with a GPS system using pseudolites instead of ground stations. Also included is a ground-based receiver which supports differential GPS tracking. For the at-sea portion of the range, there is no GPS solution defined due to the complexity of providing pseudolite coverage over the water range. One final difference between the near-term ranges is that the GPS range does not require the no-drop bomb scoring unit, since it (GPS range) provides sufficient accuracy to preclude the need.

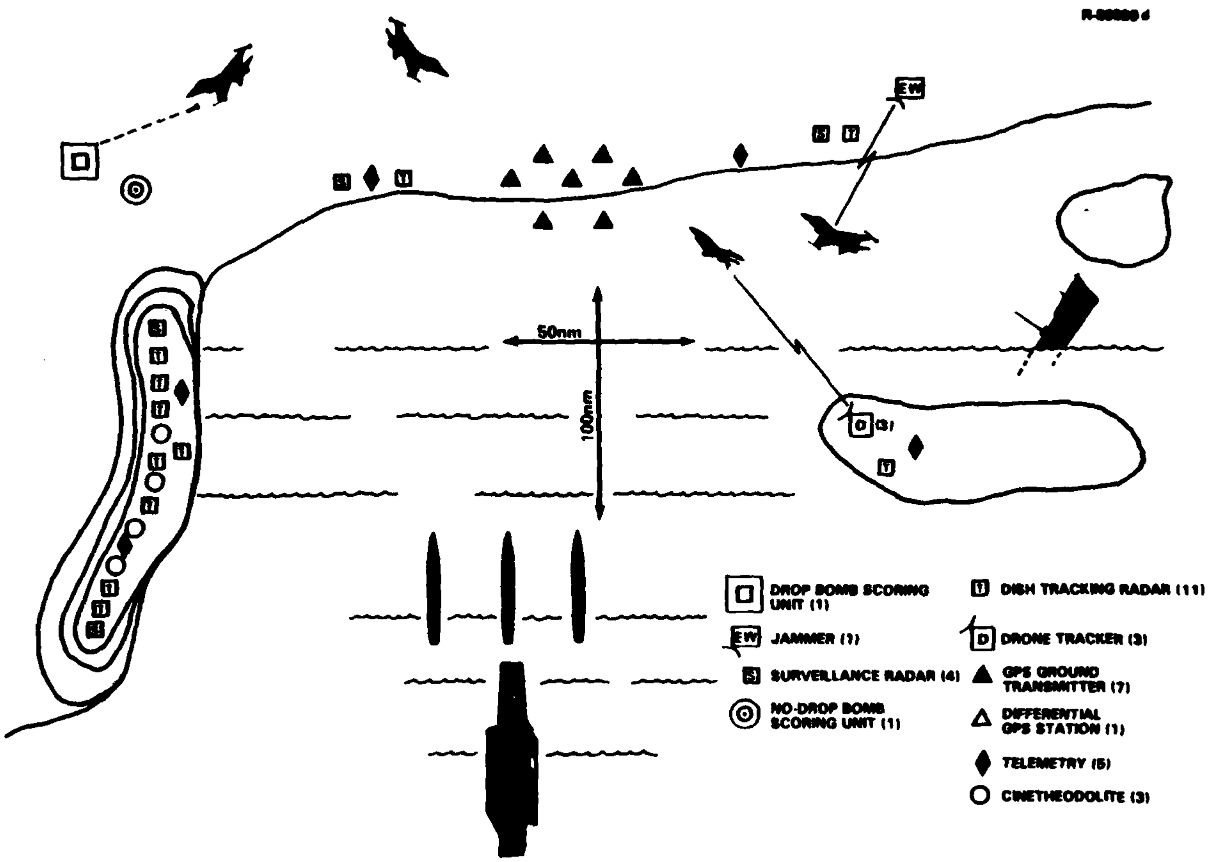


Figure 9.3-1 Sea-Based Weapons Generic Training Range (Fixed Baseline): Near-Term GPS Option

<u>Far-Term Range</u> - The far-term GPS range eliminated many of the resources required by the far-term non-GPS range. Most radars and cinetheodolites, all non-GPS multilateration ground stations, and all but two GPS ground stations (pseudolites) are removed. The requirement for a telemetry/control data link requires that the towers be retained for line-of-sight communications. The number of ground towers is reduced by two thirds since simultaneous line-of-sight from a vehicle to three towers is not required for the GPS range. A differential GPS station is added to the complement of equipment. The reason for the reduction in instrumentation is that the

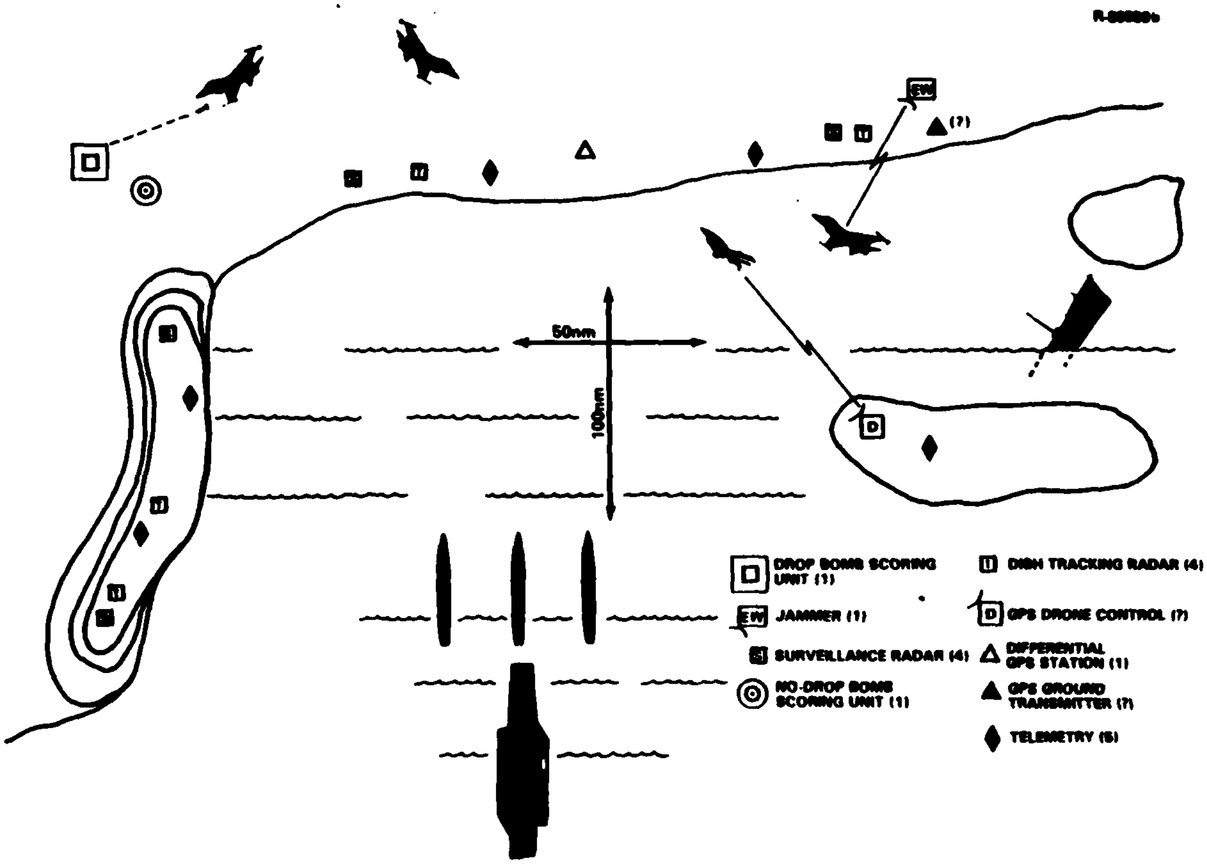


Figure 9.3-2 Sea-Based Weapons Generic Training Range (Fixed Baseline): Far-Term GPS Option

at-sea exercises no longer require the fixed base resources to obtain TSPI information.

Table 9.3-1 contains a comparative list of resources used for near- and far-term, non-GPS and GPS ranges. The surveillance radars, EW jammer and drop bomb scoring unit are required for all ranges. However, GPS eliminates the need for the no-drop bomb scoring unit.

TABLE 9.3-1
SEA-BASED WEAPONS (FIXED BASELINE)

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	7	GPS Equipment	1	---
Drone Control Station	3	3	Differential Station	1	---
TLM/C² Data Link	3-4	10	Geoceiver	1	---
Tracking Radar			Timing Receiver	1	---
Dish	11	11	Translator Receiver	1	---
Optics	3	3	GT	2†	---
Bomb Scoring Unit	2	2	Surveillance Radar	4	4
			Test Article Equipment	Yes	Yes
			†EW Adjunct		

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	50	GPS Equipment	6	---
Drone Control Station	6	6	Differential Station	1	---
TLM/C² Data Link	15-20	56	Geoceiver	1	---
Tracking Radar			Timing Receiver	1	---
Dish	4	4	Translator Receiver	7	---
Phased Array	---	2	GT	2†	---
Optics	---	3	Surveillance Radar	4	4
Bomb Scoring Unit	1	2	Test Article Equipment	Yes	Yes
			†EW Adjunct		

9.3.2 GPS Range Capabilities

The near- and far-term GPS TSPI capabilities associated with the configurations chosen for each of the test categories are shown in Tables 9.3-2, through 9.3-5. Each table also shows the requirements for the vehicle and identifies specific GPS hardware configurations.

TABLE 9.3-2

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline

Generic Test Category: Aircraft

TSPI Configuration Number: 1. (Onboard or Pod P-Code Receiver-Differential Mode)
2. (Pod Plus Operational P-Code Receiver-Differential Mode)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	25	7,12	7,12
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	15	0.06,0.11	0.06,0.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	5	5	5
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	10-25	2,4	2,4
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	(2-15)†	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	SVT-16, POS-20	SVT-8 POS-12	SVT-16, POS-20
• Coverage			
Altitude - kft	0.1-60	0.2-60	0-60
Distance - nm	50 x 100	30 x 30	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Over-land capability only.

†Attitude <2 deg; acceleration <0.5 g; roll rate <5 deg/sec.

TABLE 9.3-3
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline

Generic Test Category: Ships

TSPI Configuration Number: 1. (Onboard Ship C/A-Code Receiver)
4. (Operational Ship P-Code Receiver)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	<3000		30,51(14,23)†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--		0.06,0.11
Timing (msec)	--		--
• Data Rate (#/sec)	0.1		1
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	<100		18,30(9,14)†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	25		0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--		--
• Number of Test Articles	25		25
• Coverage			
Altitude - kft	0		0
Distance - nm	50 x 100		50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**No near-term capabilities.

†P-code receiver.

TABLE 9.3-4
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline

Generic Test Category: Missiles (A-A, A-S, S-A)

TSPI Configuration Number: 3. (Onboard C/A-code Translator)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	--	30,51	30,51
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--	0.06†-0.65, 0.11†-1.10	0.06†-0.65, 0.11†-1.10
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	50	18,30	18,30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	0.1-20	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	2	2	2
• Coverage			
Altitude - kft	0-60	0.2-60	0-60
Distance - nm	50 x 100	30 x 30	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Over-land capability only.

†Only with IMU.

TABLE 9.3-5

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Fixed-Baseline

Generic Test Category: Drones

TSPI Configuration Number: 3. (Onboard C/A-code Translator) - Near Term
1. (Onboard C/A-code Receiver) - Far Term

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	200	30,51	30,51
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	--	0.06†-0.65, 0.11†-1.10	0.06†-0.65, 0.11†-1.11
Timing (msec)	--	--	--
• Data Rate (#/sec)	10	10	10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	200	18,30	18,30
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	--	0.02,0.03	0.02,0.03
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	6	3	6
• Coverage			
Altitude - kft	0-60	0.2-60	0-60
Distance - nm	50 x 100	30 x 30	50 x 100

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Over land only.

†Only with IMU.

Aircraft - The real-time TSPI requirement for aircraft forces the use of a multi-channel P-code receiver coupled to an inertial measurement unit (IMU) which provides attitude information (see Figs. 3.4-1, 3.4-2). For post-test accuracies, the normal P-code processing is of sufficient accuracy for normal ACM; however, differential operation is necessary when no-drop bomb scoring is required.

The near-term capability is available only for over-land or near-shore exercises. There is no near-term GPS capability provided for the broad over-water range. The low altitude capability is limited to 200 feet since ground-based pseudolites suffer from the same line-of-sight limitations as the multilateration systems.

Ships - A C/A-code receiver is all that is required to meet the TSPI requirements (see Fig. 3.4-4). Again, no near-term GPS solution is available over the broad water range because of the limitations of ground-based pseudolites.

Missiles - The C/A-code translator configuration (see Fig. 3.4-3) for A-A, A-S and S-A missiles was chosen because of volume constraints. Furthermore, the lower cost of a translator is an attractive inducement for an expendable resource. In addition, all accuracy requirements are easily met using the translator. The near-term coverage constraints in both distance and altitude result from the constraints of a land-based multilateration concept requiring line-of-sight to the test vehicle.

Drones - A C/A-code translator or receiver in the drone can meet the required TSPI accuracies (see Figs. 3.4-3 and 3.4-1 respectively). However, the use of a translator precludes the use of onboard TSPI information for vehicle

navigation purposes during those segments of flight that are over-the-horizon. Therefore, the choice of the translator in the near term strictly reflects the expectation that receivers will be limited by volume constraints in most instances in this time frame and that receivers should be the first choice where space permits. As in previous applications, any near-term capability is constrained to over-land or near-shore exercises.

9.3.3 GPS Application Issues

To successfully develop a GPS instrumentation system for use on the Sea-Based Weapons, Fixed-Baseline Generic Range, several issues, discussed below, must be addressed.

Antenna Masking - The GPS instrumentation on board the test vehicle requires an antenna system which can maintain line-of-sight to the GPS satellites as well as to ground pseudolites where they are used. With both missiles and drones, a conformal antenna wrapped around the diameter of the vehicle can help meet the line-of-sight requirements. For the aircraft configuration with the receiver mounted in a pod under the wing, airframe masking will result during certain maneuvers, but the effects of these signal drop-outs can be minimized through the use of an inertial system. This system (which is needed to provide aircraft attitude information anyway) can supply aiding to the GPS receiver to allow it to coast through those time periods where signals are lost. When the GPS signal is once again in view of the antenna, the aided GPS receiver can more quickly reacquire the waveform and again be the primary source of TSPI information.

Telemetry Bandwidth - For any exercise with a large number of participants, it can be expected that a large portion

of the allowable telemetry spectrum will be used. This bandwidth problem is compounded through the use of missile translators, which each require approximately 3 MHz bandwidth. Two missiles being flown simultaneously require an addition of 6 MHz of allowable spectrum bandwidth to the normal exercise frequency allocations. The problem is not based on hardware constraints but rather on the frequency management plan constraints.

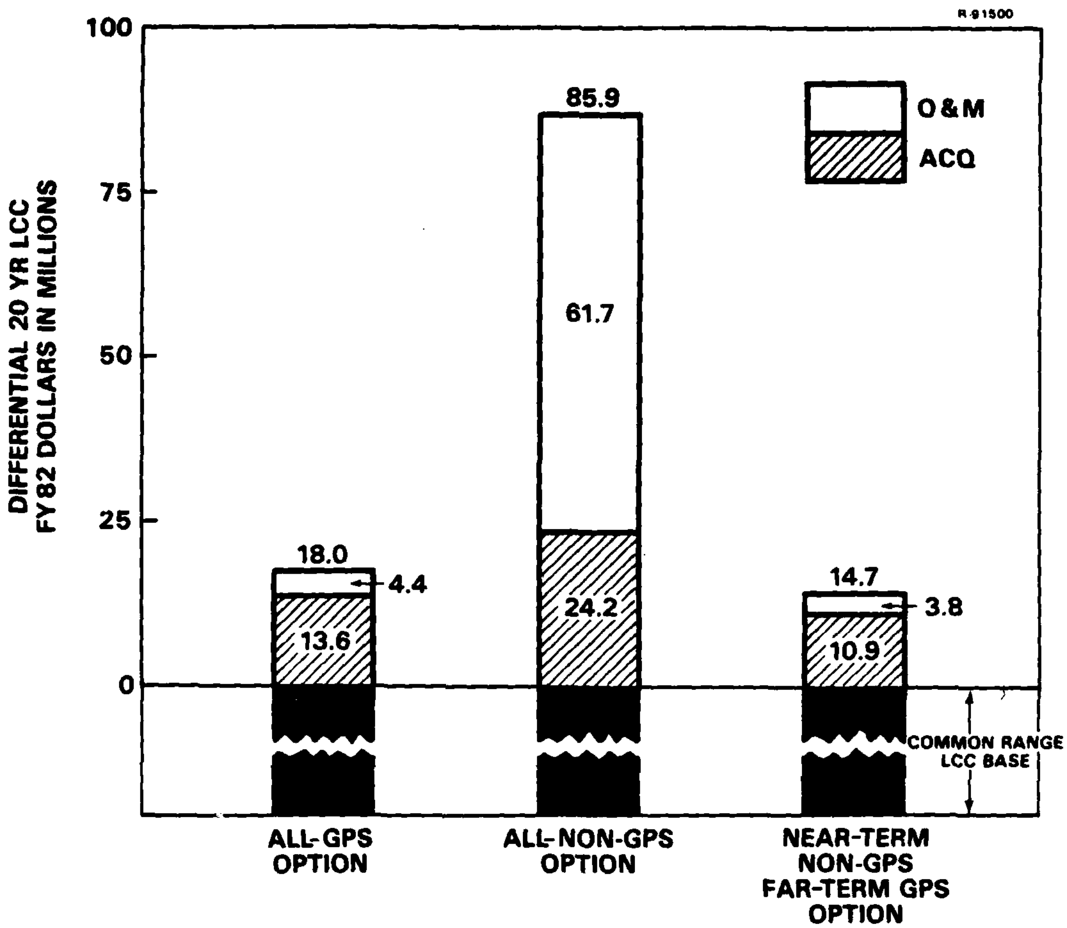
Packaging - The most severe packaging constraint is imposed by small diameter missiles. Usually the only available space for test instrumentation is in the warhead section. Since a small missile necessarily carries a small warhead, there is not much room for instrumentation. Yet, a destruct system, missile telemetry system, and a GPS translator must be packaged to fit in this small volume. This volume constraint imposes a significant burden on the package designers to ensure that all equipment required can be successfully integrated into the missile.

Far-term subscale drones may also pose a packaging problem since the limited volume must contain a destruct system, parachute, C^2 system as well as the GPS receiver, which is significantly larger than a translator.

Integration - New Navy aircraft such as the F-18 are being configured with 1553 data bases and built-in multilateration equipment. Until operational GPS equipment is integrated into the aircraft, this could present a relatively unique integration issue.

9.4 LIFE-CYCLE COST COMPARISON

The differential 20-year life-cycle cost comparison of the all-GPS option versus the all-non-GPS and the near-term non-GPS/far-term GPS (mixed) is shown in Fig. 9.4-1. The cost



- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based On Consolidated Buy

Figure 9.4-1 Sea-Based Weapons (Fixed Baseline) Range LCC Comparison

comparison was based on the cost elements presented in Section 4.2 and the equipment by numbers summarized in Table 9.3-1. The major contributors to cost in the all-GPS option are the development, acquisition and O&M of GPS range equipment, which include inverted range items, and the short-range translators and for the test articles.

For the all-non-GPS option, costs are driven by the acquisition of user equipment transponders, the O&M of a multilateration system retained in the far term, and the acquisition and O&M of two single-faced, phased array radars in the far term. The costs for the mixed option reflect lower acquisition and O&M costs because GPS equipments are not purchased and maintained until the far term.

For the Fixed-Baseline Range, the GPS options are clearly less expensive than the all-non-GPS option and there are no reasonable sensitivity calculations which can be made that will alter that conclusion.* Although there is a small cost advantage to postponing the commitment to GPS until the far term, the cost differential between the all-GPS option and the mixed option is not large enough to make that decision based on cost alone.

9.5 GPS RANGE EFFECTIVENESS EVALUATION

The effectiveness of the near- and far-term GPS ranges relative to the comparable non-GPS options is shown in Tables 9.5-1 and 9.5-2. The over-land portion of the range (Table 9.5-1) relates to the Navy Air training using a multilateration system for TSPI measurements. The at-sea portion of the range (Table 9.5-2) relates to Navy OT&E as well as training where ships constitute a significant percentage of participants in the exercise, and training radars and optics provide the major source of TSPI measurements.

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*Sensitivity analyses were performed by varying GPS pseudolite, translator and receiver costs by ±25%, varying phased array and multilateration system costs by ±25%, and by varying translator and receiver quantities from their nominal values to maximum and minimum values based on the spread evidenced in historical range usage.

TABLE 9.5-1

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING
(SEA-BASED, OVER-LAND TRAINING RANGE)

Generic Range: Sea-Based Weapons (Over Land)
Test Category: Aircraft, Missiles, Drones

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE* NEAR TERM	GPS RELATIVE ADVANTAGE* FAR TERM	PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
DRIVERS:				
• Real-Time Accuracy	0	0		
• Post-Test Accuracy	0	0		
• Broad Coverage	0	0		
• Low Altitude Coverage	0	0		
• Number of Players	0	0		
• Data Rate	0	0		
CONSIDERATIONS:				
• Integration	0	0		
• Technical Risk	-	-	Aircraft, Missiles	A/C Pod Masking, Missile Packaging
• Growth Potential	+	+	Aircraft, Missiles, Drones	Accuracy, Broader Coverage
• Standardization	0	+	Aircraft	Reduced Number & Type of Resources
• Portability	0	+	Aircraft	Fewer Ground Links Required
• Availabilty	0	+	Aircraft	Better MTBF
• Data Timeliness	0	0		
GPS APPLICABILITY	LOW	MODERATE	GPS NOT A CLEAR WINNER	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

<u>Over-Land Range Effectiveness Evaluation</u> - Table 9.5-1 indicates that the accuracy requirements are met by both GPS and non-GPS ranges in the near and the far term. For that matter, all "Driver" Measures of Merit show the GPS ranges to be comparable to non-GPS ranges. Only the "Considerations" Measures of Merit show any advantage or disadvantage for the GPS range. The latter involves technical risks (aircraft antenna masking and instrumentation packaging on small missiles), but the former includes growth potential (due to the increased TSPI accuracy available using a GPS system), standardization, portability and availability (because of the reduction in required far-term resources).

TABLE 9.5-2

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING
(SEA-BASED, AT-SEA TRAINING RANGE)

Generic Range: Sea-Based Weapons (At Sea)
Test Category: Aircraft, Missiles, Drones

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE* NEAR TERM	GPS RELATIVE ADVANTAGE* FAR TERM	PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
DRIVERS:				
• Real-Time Accuracy	N/A	+	Aircraft, Drones	GPS Meets Requirements
• Post-Test Accuracy		■	Missiles, Aircraft, Drones	
• Broad Coverage		+	Aircraft, Missiles, Drones	Multipath, Refraction
• Low Altitude Coverage		0		
• Number of Players		0		
• Data Rate		0		
CONSIDERATIONS:				
• Integration	N/A	0		
• Technical Risk		-	Aircraft, Missiles	Pod Antenna Masking, Packaging Accuracy; Position (Drones), Velocity (Missile)
• Growth Potential		+	Missiles, Drones	
• Standardization		0		
• Portability		0		
• Availabilty		0		
• Data Timeliness		0		
GPS APPLICABILITY	*N/A*	*HIGH*	*GPS Meets OT&E Requirements*	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

Although there is no compelling reason to use a GPS range for over-land exercises from the point of view of requirements, there are enough qualitative reasons to justify applicability to this portion of the Sea-Based range.

<u>At-Sea Range Effectiveness Evaluation</u> - Table 9.5-2 shows the GPS effectiveness for the at-sea portion of the Sea-Based Range. There is no comparison provided for the near-term ranges since this is no reasonable GPS capability available due to the need for pseudolites at sea. In the far term, however, the table shows significant advantages for a GPS range over a non-GPS range. Both real-time and post-test accuracy requirements are met by the GPS system whereas they are not

met by the non-GPS tracking system at long ranges. Low altitude coverage down to sea level is also provided by GPS although it is constrained by a line-of-sight data link back to shore. As in the over-land portion of the range, the technical risk considerations are aircraft antenna masking and missile packaging while the growth potential for missiles and drones is based on accuracy capabilities; drone formations can be held tightly, and missile performance analysis against multiple targets can be improved based on the tighter accuracy capabilities.

From the range comparisons described in this subsection, it is clear that there is a high GPS applicability to the at-sea portion of the Sea-Based Range. This result is based on the fact that instruments using range/angle/angle measurements for TSPI information have an inherent accuracy degradation as a function of range between the vehicle and the instrument. As discussed in the next chapter, a cooperative tracking system (CTS) *does not* suffer from angle measurement limitations. This same system could have been specified for the at-sea portion of the Sea-Based Weapons, Fixed-Baseline Range, but it would not have been consistent with the pattern ranges.

10. SEA-BASED WEAPONS, MOVING-BASELINE GENERIC RANGE ANALYSIS

The generic Sea-Based Weapons, Moving-Baseline Range is patterned after the Mobile Sea Range. The purpose of this range is to provide effective training in fleet exercises confined to an area of 350 by 500 nm.

10.1 TSPI REQUIREMENTS ASSESSMENT

TSPI requirements for the Moving-Baseline Range are given in Table 10.1-1 for two different range uses: training exercises and OT&E. For the former, all participants require a TSPI accuracy of 200 feet horizontally and 3% of altitude, while the data rate is variable and a function of vehicle dynamics. Although there are no specific requirements given in the data base for OT&E, requirements were developed from accuracies used in the Fixed Baseline case based on the assumption that weapons test analysis would require a particular accuracy independent of whether the test was performed over land or at sea.

Ships - Because ship exercises are typically analyzed in near-real-time, post-test and real-time accuracy have the same requirement (Table 10.1-1). The two hundred foot accuracy is needed during simulated or actual A-S or S-A missile firings while the requirements for the data rate (0.1 Hz) and number of test articles (25) are the same as that used for the Fixed Baseline Sea-Based Weapons Range.

TABLE 10.1-1
TSPI REQUIREMENTS*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training, OT&E)

TEST PARAMETER	TRAINING ALL VEHICLES	OT&E			
		SHIPS	AIRCRAFT	DRONES	MISSILES (A-A,A-S,S-A)
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	200,§	200	25	200	1000**
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	---	---	15	---	---
Timing (msec)	---	---	---	---	---
• Data Rate (#/sec)	0.1-10	0.1	5	10	10
• Post-Test Accuracy (1σ)					
Position (x,y),(z) - ft	200,§	200	25	200	50
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	---	---	15†	---	(0.1-20)††
• Scoring Accuracy (ft-1σ Circ)	---	---	---	---	---
• Number of Test Articles	60	25	SVT-16, POS-20	6	2
• Coverage					
Altitude - kft	0-60	0	0.1-60	0-60	0-60
Distance - nm	350 x 500	350 x 500	350 x 500	350 x 500	350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Estimated.

†Attitude <2 deg, acceleration <0.5 g, roll rate <5 deg/sec.

††For Midcourse Inertial Guidance.

§3% of altitude.

Aircraft - The aircraft requirements shown in the table are essentially the same as those used for the Fixed-Baseline Range. The rationale for this choice is that Combat Air Patrol (CAP) exercises will result in both simulated and real missile firings. The performance analysis should be quite similar for both ranges and hence be constrained to the same accuracy requirements.

Drones - The TSPI accuracy requirement shown for drones is also the same (except for coverage distance) as those used for the Fixed-Baseline Range. This accuracy constraint is

partially set by the need for drone formation control. When the drones are not flying in formation, the accuracy requirement can degrade.

Missiles - The missile TSPI accuracies given in Table 10.1-1 are based on OT&E requirements where weapon system performance will be analyzed. The stringent post-test velocity accuracy shown is needed for the analysis of those missiles which have an inertial midcourse guidance system.

10.2 GENERIC NON-GPS RANGE BASELINES

This section described the instrumentation used on the non-GPS test ranges. It also defines the instrumentation TSPI capabilities and relates them to the requirements.

10.2.1 Instrumented Range Description

The generic baseline range covers an area of 350 x 500 nautical miles. TSPI measurements are obtained via a cooperative tracking system (CTS). The range instrumentation is carried on board the participants in the exercise, which minimizes the fixed assets necessary to support both training and OT&E. A master substation is placed on board a ship designated as the mobile range operations center (MROC). Its function is to interrogate and track all participants. Participant instrumentation packages (PIP) are carried by each vehicle and provide it with the capability to relay, report, or respond (R^3).

Figure 10.2-1 depicts the range, and types or exercises supported by the CTS. The system hardware described above provides a capability to get TSPI information from a particular vehicle by (relayed) multilateration measurements from

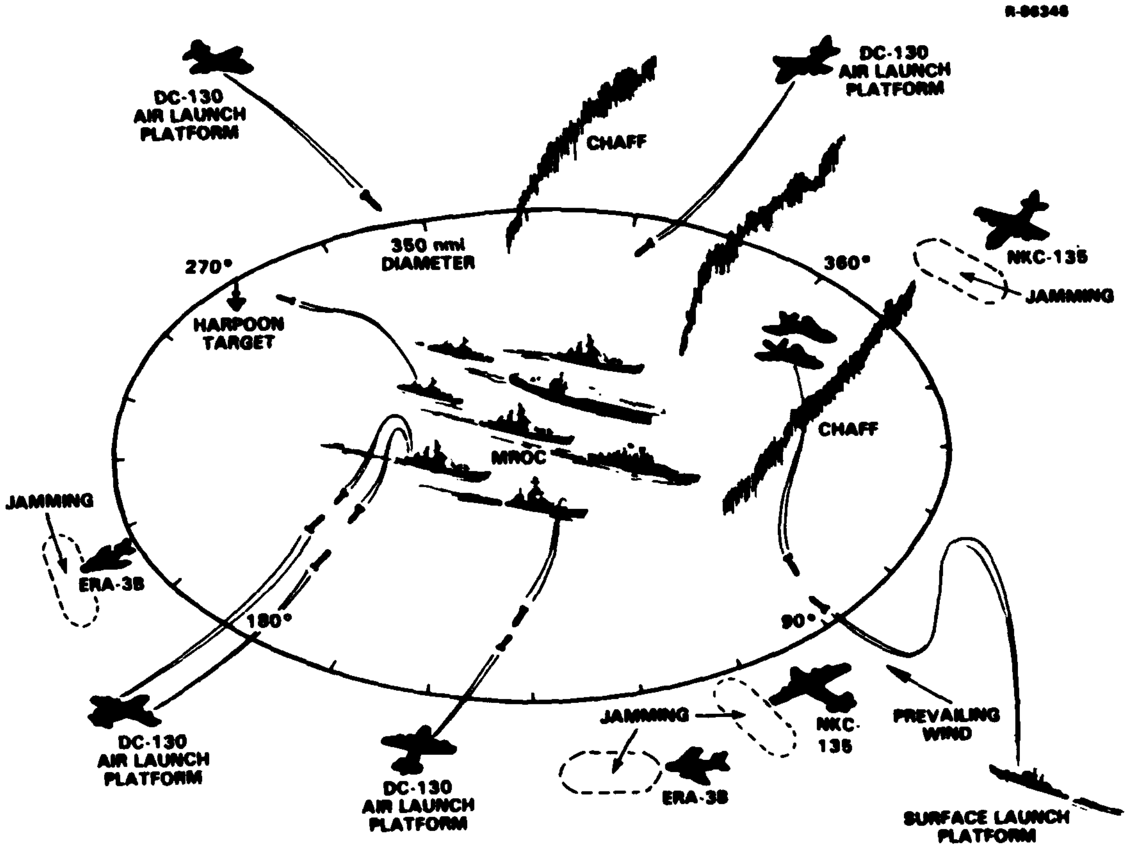


Figure 10.2-1 Sea-Based Weapons Generic Training Range (Moving Baseline)

other participant vehicles. The system also provides the capability to receive status data from all participants, and to control drones.

10.2.2 <u>Non-GPS Range Capabilities</u>

In Section 10.1, the TSPI requirements were developed for this generic range. The requirements were divided into two categories: those necessary for training, and those for

OT&E. Table 10.2-1, and 10.2-2, define the CTS capabilities for each category and relate them to the requirements.

TABLE 10.2-1
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training)

Generic Test Category: All Vehicles

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	200,†	200,100-†	200,100-†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--	--	--
Timing (msec)	--	--	--
• Data Rate (#/sec)	0.1-10	VARIABLE	VARIABLE
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	200,†	200,100-†	200,100-†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--	--	--
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	60	40	60
• Coverage			
Altitude - kft	0-60	0-60	0-60
Distance - nm	350 x 500	350 x 500	350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

†3% of altitude.

All TSPI data for both training and OT&E is obtained from the CTS, which has a 200 foot horizontal accuracy and a vertical accuracy which is three percent of the participant altitude. The only difference between near-term and far-term

TABLE 10.2-2
REQUIREMENTS VS NON-GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (OT&E)

Generic Test Category: All Vehicles

TEST PARAMETER	TSPI REQUIREMENT	NON-GPS TSPI CAPABILITY	
		NEAR TERM	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	25-50	200,100-†	200,100-†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	15	--	--
Timing (msec)	--	--	--
• Data Rate (#/sec)	0.1-10	VARIABLE	VARIABLE
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	25-50	200,100-†	200,100-†
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	(0.1-20)**	--	--
• Scoring Accuracy (ft-1σ Circ)	--	--	--
• Number of Test Articles	60	40	60
• Coverage			
Altitude - kft	0-60	0-60	0-60
Distance - nm	350 x 500	350 x 500	350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**Midcourse inertial guidance.

†3% of altitude.

capabilities relates to the number of participants the system is capable of handling. For training purposes, the CTS capabilities provide the needed accuracies to meet the requirements.

For OT&E exercises, the TSPI measurement capability satisfies the accuracy requirements for ships and under some

circumstances, drones. The required drone accuracy is met up to an altitude of 6500 feet, after which the vertical accuracy requirement is no longer met. Required aircraft and missile TSPI accuracies necessary for weapon systems tests are not met by the CTS.

The CTS does have the capability to meet both the coverage and data rate requirements imposed by the generic range. Furthermore, the number of participants required (60 vehicles) is also met by the CTS in the far term under the condition that the mix of high and low dynamics vehicles is consistent with the tabulated maximum number of participants for each vehicle category.

10.3 GPS SCENARIO DEVELOPMENT

This section describes the GPS baseline range in the same manner as that used in Section 10.2 for the non-GPS range. Two additional aspects will also be covered, a comparison of GPS vs non-GPS resources, and the issues associated with implementing a GPS-based range.

10.3.1 Instrumented GPS Range Descriptior

The instrumented GPS range looks essentially identical to the non-GPS range because all range resources for the non-GPS range are also required for the GPS range. The GPS range requires three additional types of equipment: GPS user equipment on each vehicle interfaced to the R^3 unit, ship-based translator receivers to accommodate GPS signal tranlations from missiles and drones, and ship-based GPS receivers.

The basic premise of this range instrumentation configuration is that the CTS will be used in a normal manner to

command and receive information from a participant; but, instead of using a timed response message to get range data, encoded GPS TSPI will be fed directly into the response message. This approach negates the need to have line-of-sight to two or more of platforms for multilateration measurements which will simplify planning as well as the communications and timing associated with the C^2 functions.

10.3.2 GPS Range Capabilities

The TSPI accuracy capabilities of the GPS range are a function of the GPS equipment used by the individual participant. Tables 10.3-1 through 10.3-4 define the vehicle instrumentation and show its corresponding far-term capability. A near-term capability is not practical due to the need for surveyed pseudolites to supplement limited satellite availabilities. In all cases, the GPS TSPI capability meets all vehicle accuracy requirements.

The actual vehicle configurations needed to meet the range requirements are given in the tables. These configurations are identical to those used in the fixed-baseline configuration, which is reasonable since the accuracy requirements used for the moving-baseline vehicles are essentially the same as those used for fixed-baseline vehicles. The explanations used in Section 9.3.2 are valid for this section and are not repeated.

10.3.3 GPS Application Issues

The issues for the Moving-Baseline Range are identical to those associated with the Fixed-Baseline Range. They have been previously addressed in Section 9.3.3.

TABLE 10.3-1

REQUIREMENT VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training, OT&E)

Generic Test Category: Ships

TSPI Configuration Number: 1. (Onboard Ship C/A-Code Receiver)
4. (Operational Ship P-Code Receiver)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	200		30,51(14,23)†
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	--		0.06-0.1
Timing (msec)	--		--
• Data Rate (#/sec)	0.1		1
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	200		18,30(9,14)†
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) - fps	--		0.02-0.03
• Scoring Accuracy (ft-1σ Circ)	--		--
• Number of Test Articles	25		25
• Coverage			
Altitude - kft	0		0
Distance - nm	350 x 500		350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**No near-term capability.

†P-code receiver.

10.4 LIFE-CYCLE COST COMPARISON

No differential life-cycle cost comparison was performed, for the Moving-Baseline Generic Range due to a lack of basic cost data for the CTS. Introduction of GPS equipments

TABLE 10.3-2
REQUIREMENTS VS GPS CAPABILTIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training, OT&E)

Generic Test Category: Aircraft

TSPI Configuration Number: 1. (Onboard or Pod P-Code Receiver)
2. (Pod Plus Operational GPS Receiver)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	25		14, 23
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	15		0.06†-0.33, 0.11†-0.55
Timing (msec)	--		--
• Data Rate (#/sec)	5		5
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	25		9,14
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	15††		(0.02-0.03)††
• Scoring Accuracy (ft-1σ Circ)	--		--
• Number of Test Articles	SVT-16, POS-20		SVT-16, POS-20
• Coverage			
Altitude - kft	0.1-60		0-60
Distance - nm	350 x 500		350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**No near-term capability.

†Only with IMU.

††Attitude <2 deg; accerlation <0.5 g; roll rate <5 deg/sec.

into the range scenario will not permit the replacement or phase-out of any existing range assets. Therefore, GPS instrumentation for this range is strictly a cost addition to the non-GPS range LCC base cost.

TABLE 10.3-3
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training, OT&E)

Generic Test Category: Missiles (A-S, S-A, A-A)

TSPI Configuration Number: 3. (Onboard C/A-Code Translator)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	1000		30, 51
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--		0.6†-0,65, 0.11†-1.11
Timing (msec)	--		--
• Data Rate (#/sec)	10		10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	50		18, 30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	(0.1-2[illegible])††		0.02-0.03
• Scoring Accuracy (ft-1σ Circ)	--		--
• Number of Test Articles	2		6-8
• Coverage			
Altitude - kft	0-60		0-60
Distance - nm	350 x 500		350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**No near-term capability.

†Only with IMU.

††For midcourse inertial guidance.

TABLE 10.3-4
REQUIREMENTS VS GPS CAPABILTIES*

Generic Range: Sea-Based Weapons, Moving-Baseline (Training, OT&E)

Generic Test Category: Drones

TSPI Configuration Number: 1. (Onboard C/A-Code Receiver)

TEST PARAMETER	TSPI REQUIREMENT	GPS TSPI CAPABILITY	
		NEAR TERM**	FAR TERM
• Real-Time Accuracy (1σ)			
Position (x,y),(z) - ft	200		30, 51
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--		0.06†-0.65 0.11†-1.11
Timing (msec)	--		--
• Data Rate (#/sec)	10		10
• Post-Test Accuracy (1σ)			
Position (x,y),(z) - ft	200		18, 30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) - fps	--		0.02-0.03
• Scoring Accuracy (ft-1σ Circ)	--		--
• Number of Test Articles	6		6
• Coverage			
Altitude - kft	0-60		0-60
Distance - nm	350 x 500		350 x 500

*Parameter ranges, where specified, reflect differing requirements for each test phase.

**No near-term capability.

†Only with IMU.

10.5 GPS RANGE EFFECTIVENESS EVALUATION

The effectiveness of the GPS range relative to the comparable non-GPS range is shown in Tables 10.5-1 and 10.5-2. The first table shows the effectiveness when the range is used for training, while the second table is pertinent to OT&E.

TABLE 10.5-1
GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

Generic Range: Sea-Based Weapons, Moving-Baseline (Training)
Test Category: Ships, Aircraft, Missiles, Drones

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE* NEAR TERM	GPS RELATIVE ADVANTAGE* FAR TERM	PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
DRIVERS:				
• Real-Time Accuracy		0		
• Post-Test Accuracy		0		
• Broad Coverage	N/A	0		
• Low Altitude Coverage		0		
• Number of Players		0		
• Data Rate		0		
CONSIDERATIONS:				
• Integration		0		
• Technical Risk		(-)	Aircraft, Missiles	Pod Antenna Masking; Missile Packaging
• Growth Potential		(+)	Aircraft	Improved Accuracy
• Standardization	N/A	0		
• Portability		0		
• Availabilty		0		
• Data Timeliness		0		
GPS APPLICABILITY	N/A	LOW	No Significant Motivation for GPS Option	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

<u>Training Effectiveness</u> - A GPS-configured range for training provides no distinict advantage over the CTS system used in a non-GPS range. Accuracy and coverage requirements are met by both systems. The technical risk consideration is worse for a GPS instrumented range, due to missile packaging and instrumentation pod antenna masking, although improved

TABLE 10.5-2
GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

Generic Range: Sea-Based Weapons, Moving-Baseline (OT&E)
Test Category: Ships, Aircraft, Missiles, Drones

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
DRIVERS:				
• Real-Time Accuracy		$\boxplus$	Drones, Aircraft	Improved Control; Meets Requirements
• Post-Test Accuracy		$\boxplus$	Drones, Aircraft	Meets Requirements
• Broad Coverage	N/A	+	All Vehicles	Only One LOS Link Required
• Low Altitude Coverage		0		
• Number of Players		0		
• Data Rate		0		
CONSIDERATIONS:				
• Integration		0		
• Technical Risk		$\boxminus$	Aircraft, Missiles	Pod Antenna Masking; Packaging
• Growth Potential		+	Drones, Missiles	Tighter Formations; Better Accuracy
• Standardization	N/A	0		
• Portability		0		
• Availabilty		0		
• Data Timeliness		0		
GPS APPLICABILITY	N/A	HIGH	Significant Motivation for GPS Option	

*GPS vs non-GPS Options

Rating Key: GPS Better +
GPS Same 0
GPS Worse -
Critical □

accuracy provides a GPS growth potential for scoring simulated missile firings.

OT&E Effectiveness - Table 10.5-2 shows the GPS effectiveness for OT&E. The major advantage of the GPS instrumented range is that it meets the accuracy requirements needed to analyze aircraft and missile performance in weapons systems tests. It also provides the needed TSPI accuracy for drones above the altitude of 6500 feet. The area coverage is extended for peripheral participants since only one line-of-sight link is required to acquire the vehicle TSPI.

The technical risk consideration is negative for GPS equipment for reasons mentioned in previous sections. Growth

potential is significant for OT&E exercises. Improved accuracy would allow tighter formation control of targets. This is especially significant for missiles with small warheads where angular resolution of multiple targets is essential for an acceptable probability of kill.

Improved real-time TSPI accuracy is also helpful for range safety considerations. Good velocity information allows quicker prediction of an anomalous missile trajectory resulting in the ability to use smaller safety corridors. This can be significant since it can allow deeper missile penetration among exercise participants.

It is clear that the GPS option is a necessary adjunct for the Sea-Based Moving Baseline range if weapons systems testing is to be performed. It is the only viable system that meets the range requirements.

11. AIRBORNE WEAPONS GENERIC RANGE ANALYSIS

The Airborne Weapon generic range for training and OT&E was modeled as a circular range with a diameter of 30 nm in the near term and 60 nm in the far term. Range topography consisted of flat terrain surrounded by moderate hills. This range was based on three primary pattern ranges: AFTFWC, UTTR and AD. Test categories using the range include drones, short-range missiles (A-to-A and A-to-S), cruise missiles, and aircraft. The range also support Electronic Warfare, Air Exercises and Training.

This chapter discusses the generic range requirements in Section 11.1. The non-GPS range baseline is contained in Section 11.2 while the GPS scenario development is provided in Section 11.3. The latter describes the generic GPS ranges and the GPS TSPI configuration selected, and discusses GPS application issues. Life-cycle costs of the non-GPS and GPS generic range options are presented in Section 11.4 with the GPS range effectiveness analysis results presented in Section 11.5.

11.1 TSPI REQUIREMENTS ASSESSMENT

The TSPI requirements given in the data base for the primary and secondary pattern ranges were accumulated by test category for each of the test parameters. The compilation of these requirements and capabilities involved the use of engineering estimates for those instances where values were not provided by the individual range documentation. Table 11.1-1 lists the requirements for all instrumentation for each test

TABLE 11.1-1

TSPI REQUIREMENTS

Generic Range: Airborne Weapons (Training, OT&E)

TEST PARAMETER	A-A			A-S			CRUISE MISSILE		EW	AIR EXERCISE/ TRAINING
	LNCH A/C	DRONE	MISSILE	LNCH A/C	DRONE	MISSILE	EN ROUTE	TER-MINAL		
Real-Time Accuracy (1σ)										
Position $(x,y),(z)$ ft	25	25	25	12-25	12-25	5	25	10	15-25	50-200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	3	3	3	3	3	3	1	0.1	3	5-15
Timing (msec)	100	100	100	50-100	50-100	100	100	100	100	50-100
Data Rate (#/sec)	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10	1-10
Post-Test Accuracy (1σ)										
Position $(x,y),(z)$ ft	<25	3[1]-25	3[1]	5	5	1-5	>25	>10	15	>50-200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	3	3	3[1]	3	3	3	1	0.1	3	5-15
Scoring Accuracy (ft-1σ Circ)	-	-	3	-	-	1-6	-	10	-	10
No. Test Articles	1-12	1-12	1-12	5-25	5-25	5-25	5-10	5-10	1-50	1-90
Coverage										
Altitude - kft	0-100	0-100	0-100	1-75	1-75	1-75	0.1-100	0.1-100	0.1-100	0.1-100
Distance - nm (diameter)	60	60	60	30	30	30	VAR	VAR	30-60	30-60

category using the Airborne Weapon generic range. The real-time accuracy requirements do not include area surveillance requirements as these radar will always be part of the range to handle non-cooperative targets.

11.2 GENERIC NON-GPS RANGE BASELINES

This section describes the instrumentation used on the non-GPS test ranges. It also defines the instrumentation's TSPI capabilities and relates them to the requirements.

11.2.1 Instrumented Range Description

The non-GPS ranges were separated into near-term and far-term ranges. Near term covers the period 1985 through 1987, far term encompasses the period 1988 through 2004. These generic ranges were designed to handle the test categories using current instrumentation (near term) and projected range improvement instrumentation (far term). The instrumentation is non-specific and is represented by a generic type of TSPI instrumentation. The non-GPS requirements for coverage provide the basis for range dimensions. Topography was considered in a general way, in that the primary candidate ranges included variations in terrain. The topography of the generic ranges could be described as having flat terrain surrounded by moderate hills. The range area design provides for both low and high level penetration routes, an area for live fire or ordnance, and an area for ACM training and no drop bomb scoring.

The test categories included in these ranges are air-to-air and air-to-surface testing, each of which includes the launch aircraft, target and ordnance (missiles). TSPI for unguided bombs was not considered in this analysis. Cruise

missiles include enroute and terminal area TSPI requirements. Electronic Warface testing includes various types of EW equipped aircraft, while Air Exercises/Training included the requirements for multiple player aircraft TSPI.

Near-Term Non-GPS Range - Figure 11.2-1 illustrates the generic range non-GPS option for the near term. The range includes the type and quantities of TSPI instrumentation systems which would be required to handle the number of players specified for each type of test mission. The multilateration system is representative of a current TSPI system using remote stations. The radar and theodolite tracking systems represent both old and new technology and are serving a number of current ranges. Quantities of theodolites were estimated using a postulated number of simultaneous test articles to be tracked based on a 4 to 1 theodolites-to-players ratio.

This near-term range is based upon a TACTS/ACMI type range which is currently in use for OT&E and training. It contains a live fire area which is contained within the range of the TACTS/ACMI system. The live fire area tracking systems are tracking radars (FPS-16 or equivalent), cine and video theodolites and laser ranging equipment. This complement of equipment is currently in use or could be provided in the near-term time period.

Far-Term Non-GPS Range - The far-term non-GPS generic range option is illustrated in Fig. 11.2-2. This range represents a modernization of a range to include extended coverage to meet specified requirements. The range consists of three phased array radars sited to cover a 60 nm diameter area and handle high interest primary test aircraft and low interest participating aircraft for air exercises, training and electronic warfare testing. Precision air-to-air and air-surface

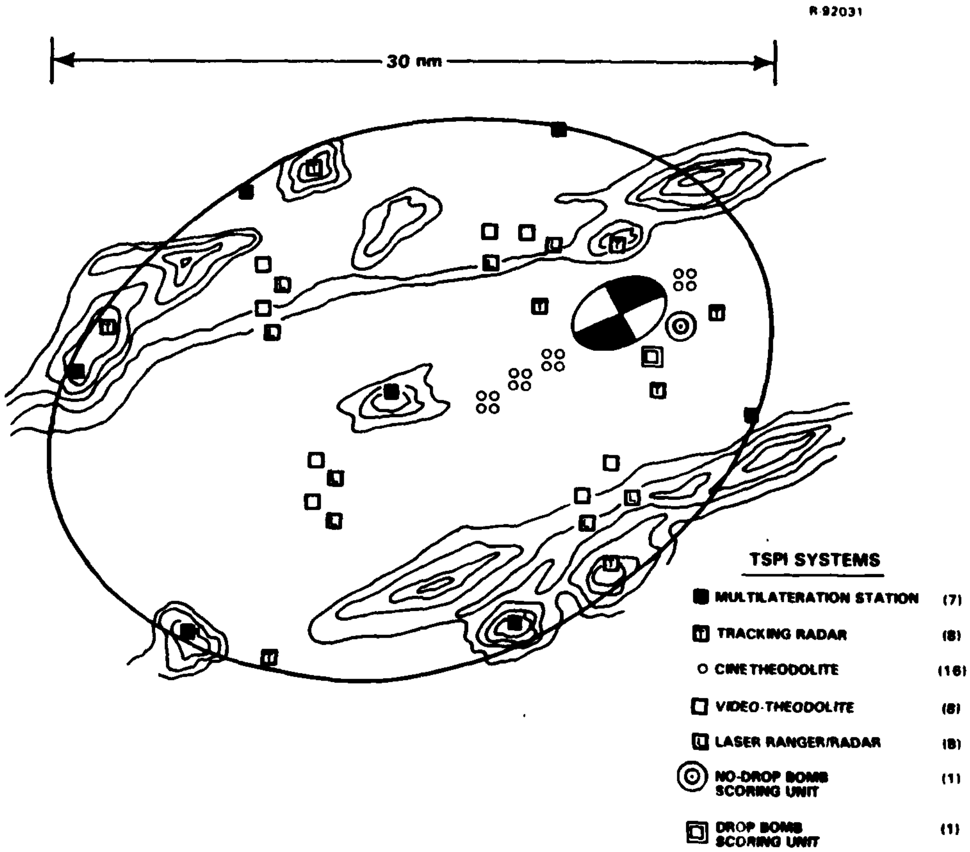


Figure 11.2-1 Generic Airborne Weapons OT&E and Training Range: Near-Term Non-GPS Option

testing is accomplished with tracking radars and theodolites. This range is patterned after the TFWC Nellis north range upgrade which uses 3 phased array radars to track the required 60-90 players. It would track podded high interest targets as well as any other noncooperative player targets.

The number of older tracking radars is reduced and replaced with more reliable laser rangers and video theodolites. The live fire area is an integral part of the range to allow tracking of launch aircraft with the phased array radars or laser rangers. Missile tracking is accomplished with video theodolites and provides accuracies for scoring or end game

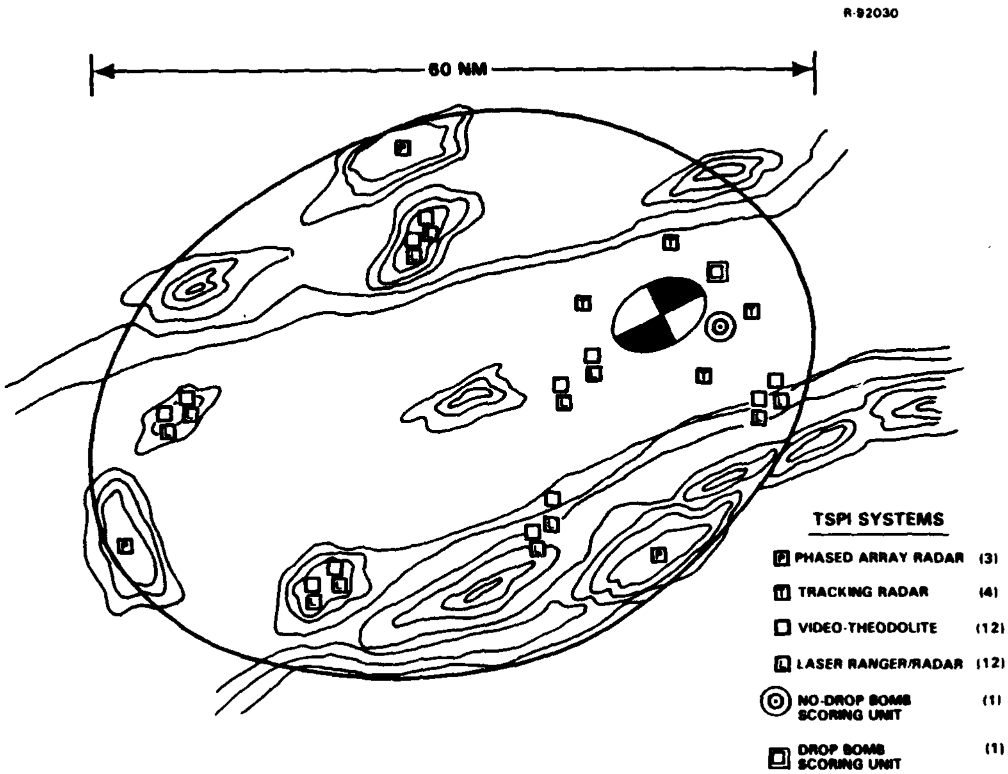


Figure 11.2-2 Generic Airborne Weapons OT&E and Training Range: Far-Term Non-GPS Option

analysis. A list of instrumentation for this option is presented in Table 11.3-3.

11.2.2 Non-GPS Range Capabilities

A TACTS/ACMI system was used as basis for the TSPI capabilities shown in Tables 11.2-1 and 11.2-2. This system has a published capability of 25 feet, but has also been measured down to 9 feet, hence the 9 feet capability. Cruise missile (enroute) real-time accuracy capabilities were estimated using the capabilities of an RMS system. Post-test accuracies were not applicable for enroute. For cruise missiles in the

terminal area, coverage values were estimated as sufficient for altitude (0-5 kft) and a 5 nm diameter area for flight termination.

Post-test accuracy capabilities were based on cinetheodolite capabilities. The real-time accuracy capabilities for A-A and A-S small missiles (armament) uses cine or video theodolite tracking. Post-mission accuracies assume cinetheodolite tracking. Because of the number of vehicles involved, the near- and far-term capabilities are condensed in Tables 11.2-1 and 11.2-2.

11.3 GPS SCENARIO DEVELOPMENT

The non-GPS requirements and capabilities provide the basis for comparison with GPS receiver and translator capabilities for GPS scenario development. The test requirements for the non-GPS test categories are compared to the GPS capability for satisfying the test requirement. The primary test parameter drivers compared are: real-time accuracy, data rate, post-mission accuracy, scoring accuracy, number of test articles and coverage in altitude and distance (volume). Other GPS receiver/translator considerations are equipment size, weight and power capacity. The performance trade-offs and the size, weight and power projections contained in Chapter 3 provide a basis for the GPS scenario development.

11.3.1 Instrumented GPS Range Description

This section describes the development of the generic GPS ranges for airborne weapons in the near and far term.

Requirements vs GPS Capabilities - A composite table of TSPI requirements vs near- and far-term GPS capabilities is

TABLE 11.2-1

NEAR-TERM NON-GPS CAPABILITIES

Generic Range: Airborne Weapons (Training, OT&E)

TEST PARAMETER	A-A			A-S			CRUISE MISSILE		EW	AIR EXERCISE/ TRAINING
	LNCH A/C	DRONE	MISSILE	LNCH A/C	DRONE	MISSILE	EN ROUTE	TERM-INAL		
Real-Time Accuracy (1σ)										
Position (x,y),(z) ft	25,75	25,75	25,75	25,75	25,75	25,75	25,75	25,75	15,25	25,75
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) fps	3	3	3	3	3	3	2	2	3	3
Timing (msec)	100	100	100	100	100	100	100	100	100	100
Data Rate (#/sec)	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10	1-10
Post Test Accuracy (1σ)										
Position (x,y),(z) ft	3[1]-25	3[1]-25	3[1]	3[1]-25	3[1]-25	3[1]	<25,75	1-3	15	<25,75
Velocity ($\dot{x},\dot{y}$),($\dot{z}$) fps	3	3	3	3	3	3	2	0.05	3	3
Scoring Accuracy (ft-1σ Circ)	-	3[1]	3	-	3[1]	1-3	-	3	-	-
No. Test Articles	1-2	1-2	1-2	1-4	1-4	1-4	1-5	1-5	1-8	20
Coverage										
Altitude - kft	1-75	1-75	1-75	1-75	1-75	1-75	0.5-55	0.5	-	5-50
Distance - nm (diameter)	30	30	30	30	30	30	VAR	VAR	-	30

1 END GAME

TABLE 11.2-2

FAR-TERM NON-GPS CAPABILITIES

Generic Range: Airborne Weapons (Training, OT&E)

TEST PARAMETER	A-A			A-S			CRUISE MISSILE		EW	AIR EXERCISE/ TRAINING
	LNCH A/C	DRONE	MISSILE	LNCH A/C	DRONE	MISSILE	EN ROUTE	TERM-INAL		
Real-Time Accuracy (1σ)										
Position (x,y),(z) ft	25,75	25,75	25,75	25,75	25,75	25,75	25,75	25,75	15,25	50-200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	3	3	3	3	3	3	2	2	3	5
Timing (msec)	100	100	100	100	100	100	100	100	100	100
Data Rate (#/sec)	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10	1-10
Post Test Accuracy (1σ)										
Position (x,y),(z) ft	3[1]-25	3[1]-25	3[1]	3[1]-25	3[1]-25	3[1]	<25,75	1-3	15	<50-200
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	3	3	3	3	3	3	2	0.5	3	5
Scoring Accuracy (ft-1σ Circ)	-	31	3	-	3[1]	1-3	-	3	-	-
No. Test Articles	1-2	1-2	1-2	1-4	1-4	1-4	5-10	5-10	1-8	60-90
Coverage										
Altitude - kft	0-75	1-75	1-75	1-75	1-75	1-75	0.5-55	0.5-55	-	.01-100
Distance - nm (diameter)	60	60	60	30	30	30	VAR	VAR		60+

1 END GAME

shown in Table 11.3-1. The GPS receiver/translator capabilities are illustrated by C/A- and P-code for non-differential and differential modes of operation. A P-code receiver will satisfy most requirements. It comes close to satisfying any currently specified real-time of post-mission scoring requirements.

TABLE 11.3-1
REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Airborne Weapons

Generic Test Category: All

TEST PARAMETER	TSPI REQUIREMENT	NEAR- & FAR-TERM GPS CAPABILITIES			
		NON-DIFFERENTIAL		DIFFERENTIAL	
		C/A	P	C/A	P
• Real-Time Accuracy (1σ)					
Position (x,y),(z) - ft	10-200,10-200	30,51	14,23	25,41	7,12
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-15,0.1-15	0.06-0.65, 0.11-1.10			
Timing (msec)	50-100	100			
• Data Rate (#/sec)	1-20	1-20			
• Post-Mission Accuracy (1σ)					
Position (x,y),(z) - ft	1-200, 1-200	18,30	9,14	6,10	2,4
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	0.1-15,0.1-15	0.02, 0.03			
• Scoring Accuracy (ft-1σ Circ)	3-10	N/A	N/A	N/A	N/A
• Number of Test Articles	1-90	6[1]-90[2]	90[2]	6[1]-90[2]	90[2]
• Coverage					
Altitude - kft	0-100	0-100+			
Distance - nm (diameter)	5-60	5-60+			

*Parameter ranges, reflect differing, requirements within test categories.

[1]Estimated limits on number of translators.

[2]Receiver quantities.

In order to illustrate which receiver, C/A-or P-code, would satisfy most of the generic range requirements, a distribution of requirements containing both real-time and post-test accuracies was derived. This distribution contained the requirements from all test categories. It was compared to the real-time and post-mission accuracies (estimated) of non-differential and differential C/A- and P-code to illustrate what percentage of the requirements would be satisfied by a C/A-or P-code receiver. The C/A- vs P-code comparison is presented in Table 11.3-2. The table illustrates, for example, that a P-code receiver in real-time differential mode would satisfy 86 percent of the requirements (ranging from 10 ft and up) and a C/A-code receiver in real-time differential mode would satisfy 69.7 percent of the requirements (25 ft and up). If for example, a range has a 25 ft real-time and a 2 ft post-mission accuracy requirement, a P-code receiver in the differential mode would satisfy both requirements.

Near-Term GPS Range - The near-term GPS range option is illustrated in Fig. 11.3-1. This range employs a pseudolite in an inverted range configuration to provide signals to the receivers because a sufficient satellite constellation will not be available until late in 1987. The pseudolites would also be available to be used with the full satellite (SV) constellation in 1988-2005 to support GPS operations in the presence of ECM, and to provide signal continuity during SV outages. The range contains reduced, but sufficient non-GPS instrumentation to satisfy expected missile tracking requirements which could not be satisfied by expending translators due to number of players, missile space, or weight and power constraints.

The range also has a data communication subsystem in the form of telemetry/C^2 data link stations. These stations will transmit and receive data from aircraft pods containing

TABLE 11.3-2

REQUIREMENTS VS GPS
(C/A- AND P-CODE) CAPABILITIES

ACCURACY REQUIREMENTS (ft)	% OF TOTAL	REAL-TIME ACCURACY CAPABILITY (ft)				POST-MISSION ACCURACY CAPABILITY (ft)			
		NON-DIFFERENTIAL		DIFFERENTIAL		NON-DIFFERENTIAL		DIFFERENTIAL	
		C/A	P	C/A	P	C/A	P	C/A	P
150+	13.9	30.51*	14.23*	25.41*	7.12*	18.30*	9.1*	6.10*	2.4*
50	20.9								
30	6.9	41.8%							
25	27.9			69.7%		69.7%			
20	2.3		72.1%				72.1%		
10	13.9				86.0%			86.0%	
5	9.3								
2	2.3								97.6%
0.5	2.3								

*Estimated GPS accuracies for uncompensated user dynamics.

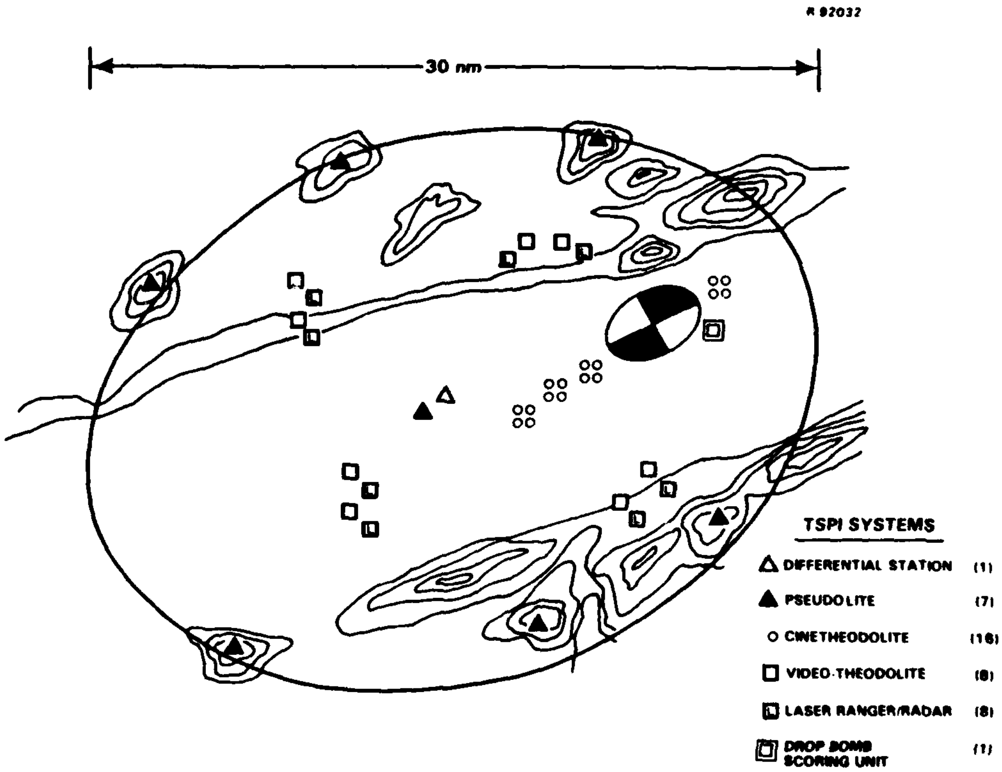


Figure 11.3-1 Generic Airborne Weapons OT&E and Training Range: Near-Term GPS Option

GPS receivers. The number of these stations has been reduced since the multilateration function of the station is no longer required in the GPS option. These stations would be placed within the range to optimize the reception of data down linked from the aircraft.

High dynamic aircraft would use either an internally-mounted or a pod-mounted multi-channel P-code receiver with a 3rd-order carrier loop or IMU aiding. High dynamic drone aircraft would use an internally-mounted multi-channel P-code receiver with appropriate aiding. For land vehicle drone application, a 1 or 2 channel P-code receiver would be used. Both near- and far-term GPS options would contain a differential receiver, this receiver would be a 1 or 2 channel receiver

operating on both L_1 and L_2 frequencies. Both ranges have an Inverted Range Control Center IRRC to control the pseudolites and a timing receiver is included to provide timing for the inverted range.

The near-term GPS option includes an inverted range, which is the equivalent of a ground-based satellite system. The pseudolites would provide continuous L_1 signals to the receivers during the period where there is not continuous overhead satellite coverage. A listing of equipments for the near- and far-term GPS options is presented in Table 11.3-3.

Far-Term GPS Range - The far-term GPS range option is illustrated in Fig. 11.3-2. This range features an expanded area and uses the satellite constellation supplemented by pseudolites on the ground. The far-term range uses a differential receiver station to obtain the best accuracy from the GPS receivers. This range also contains non-GPS missile tracking instrumentation to fulfill those precision requirements which may not be satisfied by the GPS translator. The range also has a data communications subsystem in the form of telemetry/C^2 data link stations which would transmit and receive data from the aircraft pods and from the central processing and control center. The number of these stations has been reduced relative to the non-GPS option since the multilateration function would no longer be required. A listing of instrumentation for this option is presented in Table 11.3-3.

Range Instrumentation Comparisons - The airborne generic range near- and far-term instrumentation options for both non-GPS and GPS are presented in Table 11.3-3. This table presents the estimated quantities of instrumentation which would be contained in each generic range option. This data is used as the basis for life cycle costing contained in Section 11.4.

TABLE 11.3-3

INSTRUMENTATION OPTION COMPARISON - AIRBORNE WEAPONS

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	7	GPS Equipment		
TLM/C² Data Link	3	---	Differential Station	1	---
Tracking Radar			Geoceiver	1	---
Dish	---	8	Timing Receiver	1	---
Laser Ranger/Radar	8	8	Translator Receiver	8	---
Video Theodolite	8	8	Pseudolite	7	--
Digital Cinetheodolite	16	16	Test Article Equipment	YES	YES
Bomb Scoring Unit	1	1	Surveillance Radar	1	1

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Tracking Radar			GPS Equipment		
Dish	---	4	Differential Station	1	---
Phased Array	---	3	Geoceiver	1	---
Laser Ranger/Radar	8	12	Timing Receiver	1	---
TLM/C² Data Link	3	---	Translator Receiver	12†	---
Video Theodolites	8	12	Pseudolite	3†	---
Digital Cinetheodolite	16	---	Test Article Equipment	YES	YES
Bomb Scoring Unit	1	1	Surveillance Radar	1	1

†EW Adjunct

11.3.2 GPS Range Capabilities

Each test vehicle is configured with a GPS complement of equipment which (in most cases) meets the TSPI accuracy requirements. All vehicles will be required to have IMU information available for receiver aiding. Aircraft and far-term targets have the GPS configuration shown in Fig. 3.4-1, and will require a ground-based differential GPS receiver to enhance

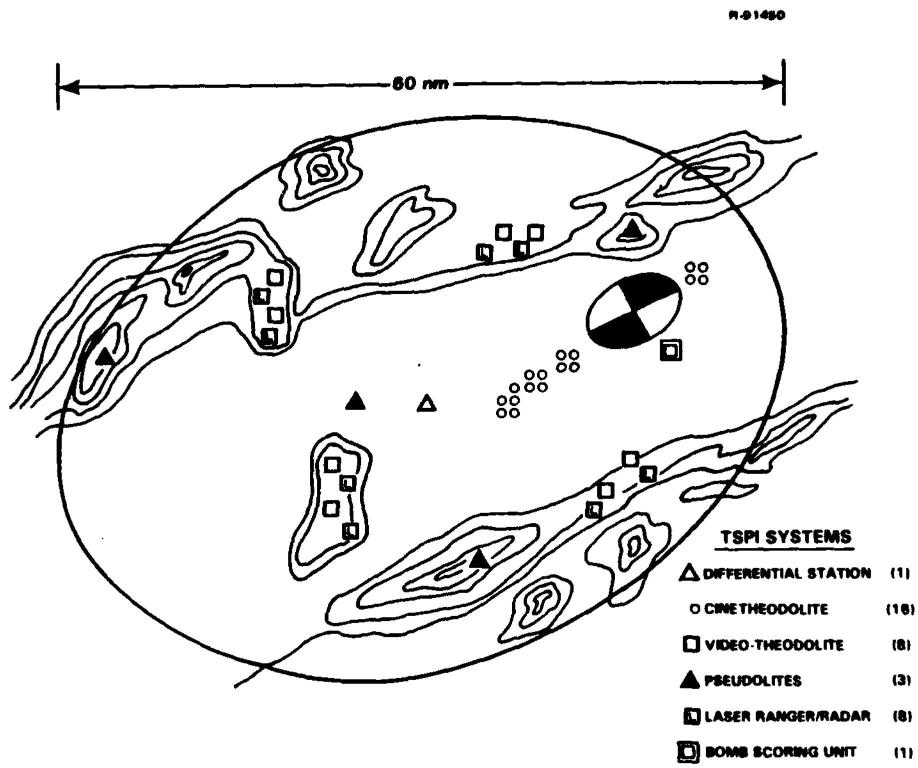


Figure 11.3-2 Generic Airborne Weapons OT&E and Training Range: Far-Term GPS Option

the P-code accuracies. Near-term targets carry a C/A-code translator (Fig. 3.4-4) which meets packaging requirements, but does not meet accuracy needs.

The ordnance will also use translators on board the missile, and may require IMU data to be transmitted with the translator signals. Ground-based differential GPS receivers are also required. Cruise missiles will carry an IMU-aided P-code receiver. Correction information from ground-based differential receivers will be needed for accuracy requirements.

A summary of the near- and far-term GPS configurations and the receiver/ translator requirements by test category is presented in Table 11.3-4.

TABLE 11.3-4

SUMMARY OF GPS SUPPORT SCENARIOS AND TSPI REQUIREMENTS

RANGE TSPI REQUIREMENT	CONFIGURATION*	
	NEAR TERM	FAR TERM
Launch Aircraft	1,2	1,2
Target	1	3
Ordnance	3	3
Cruise Missiles	3	1
EW Missiles	1,2	1,2
Exercise JT&E	1,2	1,2

*Numbers correspond to configurations in Section 3.4.

11.3.3 GPS Application Issues

This section addresses the various issues which have been identified in the application of GPS instrumentation to the Airborne Generic range. The risk and/or complexity of these issues has been subjectively rated as low, medium or high, if, <u>low</u> has little or no risk/complexity; <u>medium</u> has a moderate risk/complexity which could affect the application, but has a workable solution; and <u>high</u> may severly impact the application and render it not usable. The applications addressed include aircraft, ordnance (missiles), drone aircraft, cruise missile, drone land vehicles, and near-term pseudolite capability.

<u>Aircraft, Medium and High Dynamic Receiver</u> - The aircraft medium and high dynamic (onboard) receiver issues are presented in Table 11.3-5. The majority of issues are rated

TABLE 11.3-5

GENERIC RANGE APPLICATION ISSUES

APPLICATION: AIRCRAFT

CONFIGURATION	ISSUE	RISK/COMPLEXITY	COMMENTS
Medium and High Dynamic Reciver	Tactical Nav Receiver Accessibility	Low-High	Service Dependent
	TSPI Receiver Size	Low-Med	Aircraft Dependent
	TSPI Receiver Weight, Power	Low	Aircraft Power Available
	Antenna Masking, ECM Operation	Med	Use Stripline Antenna
			INS & GT May Allow Operations in ECM With FPRA
	TSPI Data Rate	Low-Med	Software Mods for IP may be Required if JPO Receiver
	Cost	Low	JPO P-Code Development Baseline
High Dynamic Pod Receiver	Tactical Nav Receiver, 1553 Accessibility	Low-High	Service and Aircraft Dependent
	TSPI Receiver Size	Med	Must Fit Aim-9 Pod
	TSPI Receiver Weight, Power	Low	Aircraft Power Available
	Antenna Masking, ECM Operation	Med	Same as Above. Can also use Pod Extension to Ease Masking
	Store Station Communications	Low-Med	Data Bus Availability Dependent
	Pod Commonality	Med	Common Receivers Possible, Pod will be Unique to Range Common System & Data Requirements
	TSPI Data Rate	Med	Must Interface With Existing Pod Communications Systems

low to medium. The Tactical navigation receiver is rated high due to service-dependent aircraft modification requirements. The use of a tactical GPS receiver interfaced with a pod will most likely not be allowed in certain aircraft. These aircraft can, however, use a pod-mounted GPS receiver.

Aircraft, High Dynamic Pod Receiver - The aircraft high dynamic pod receiver issues are presented in Table 11.3-5. The majority or issues are rated low to medium. The accessability of an aircraft 1553 bus to include the Tactical GPS receiver data will most likely not be allowed due to restrictions on aircraft modifications applicable to operational service aircraft. These aircraft may, however, be fitted with a pod-mounted high dynamic receiver.

Missile, High Dynamic Translator - These issues are presented in Table 11.3-6. The risk and complexity of installing a translator in a small missile airframe is rated as high and the use of a translator will be dependent upon the translator trade-offs discussed in Section 3. If used, a translator will be applied to ranges where the number of players will be limited (6 or less) and accuracy capabilities of the translator system will be sufficient for all specified requirements.

Drone, Aircraft High Dynamic Receiver - The drone aircraft high dynamic receiver issues have been rated low to medium. Current receiver designs will have to be reduced in size to fit the family of drone vehicles, and will most likely not be available for near-term applications. These issues are presented in Table 11.3-7.

Drone, Aircraft High Dynamic Translator - The issues related to a high dynamic translator application to a drone aircraft are presented in Table 11.3-7 and are rated low to

TABLE 11.3-6

GENERIC RANGE APPLICATION ISSUES

APPLICATION: MISSILE

CONFIGURATION	ISSUE	RISK/COMPLEXITY	COMMENTS
High Dynamic Translator (C/A Code) Small Missiles	Power	High (Low-Med)	Missile Dependent, Will Need Batteries
	Size	Med-High(Low-Med)	Missile Dependent-Space Available
	Weight	Low-Med	Missile Dependent
	IMU Size, Weight, & Power	High	Missile Dependent
	Antenna Coverage	Low-Med	TWA in Development
	Real Time IMU Aiding	High	Requires Synchronization With GPS Data
	Bandwidth	High	1-2 Missiles With P-Code; 4-6 With C/A
	Accuracy	Low (High)	C/A- Code Estimated Accuracy Does Not Meet Requirements/Capabilities

TABLE 11.3-7
GENERIC RANGE APPLICATION ISSUES
APPLICATION: DRONES, AIRCRAFT

CONFIGURATION	ISSUE	RISK/COMPLEXITY	COMMENTS
High Dynamic Receiver	Size	Low-Med	Vehicle Dependent
	Weight and Power	Low	Drone Power Probably Adequate
	Antenna Masking, ECM Operation	Med	Same as for Aircraft Receiver Option
	Initialization	Low	Mother-Daughter Interface Required for "M Set" Option
	Cost	Low-Med	Limited "M Set" Development Baseline
	TSPI Data Rates	Low-Med	Low Data Rates from "M Set"
High Dynamic Translator P-Code (C/A-Code)	Power	Low-Med (Low)	Vehicle Dependent
	Size and Weight	Low-Med	Vehicle Dependent
	IMU Size, Weight, Power	Low-Med	Vehicle Dependent
	Antenna Masking, ECM Operation	Med	Same as for Aircraft*
	Real-Time IMU Aiding	High	GPS/IMU Data Synchronization
	Cost	Med-High (Low)	New Development for P-Code Translator, Translator Receiver (C/A-Code being Developed)
	Signal Bandwidth	High	May Limit use to 1 or 2 Vehicles (4-6 Vehicles)

*Translator antenna gain required is function of ground antenna gain.

high depending on the code used in the translator. The translator performance trade-offs discussed in Section 3 will have to be considered for translator application in drone aircraft.

Cruise Missile Receiver - The applications issues for the cruise missile are presented in Table 11.3-8. The risks and complexity are rate low to high. High risk areas are associated with near term enroute coverage requirements using pseudolites. The number of required pseudolites and related cost would most likely preclude their use for enroute TSPI coverage. This risk would decrease to low in the far term with the use of a full satellite constellation. Near-term coverage using pseudolites at way points and in the terminal areas is feasible if contiguous enroute coverage accuracy is not required.

Drone, Land Vehicle Low Dynamic Receiver - The issues relating to the drone land vehicle low dynamic receiver are presented in Table 11.3-9. The only risk issue which was rated as possibly high is terrain masking in the near term application using pseudolites. This risk is generally terrain-dependent for any specific range and a cost factor to consider. In the far-term period, the risk should be reduced to low with the use of a full constellation of satellites.

11.4 LIFE-CYCLE COST COMPARISON

For the Generic Airborne Systems OT&E/Training range, the differential 20-year life-cycle cost comparison of the all-GPS option versus the all-non-GPS option and the near-term non-GPS/far-term GPS option (mixed option) is shown in Fig. 11.4-1. The major contributors to cost in the all-GPS option are the

TABLE 11.3-8

GENERIC RANGE APPLICATION ISSUES

APPLICATION: CRUISE MISSILE

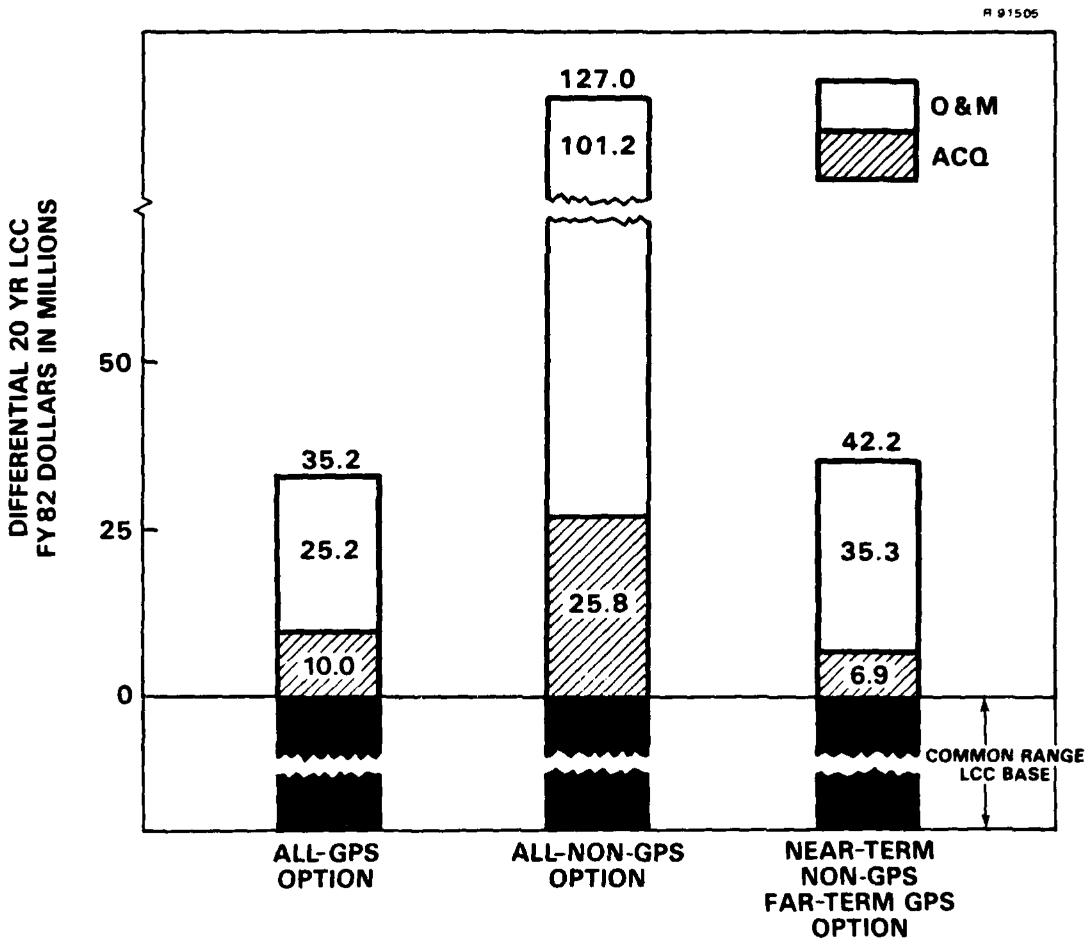
ISSUES	RISK/ COMPLEXITY	COMMENTS
Receiver		
Size, Weight	Low-Med	Warhead Volume Sufficient?
Power	Low-Med	Requires Battery + Missile Power
Data Bandwidth	Low	P-Code Plus Telemetry
Antenna Design	Low-Med	Finite Area Available for Antennas
Masking	Low	Roll Stabilization Limits Masking to Terrain Environment
Near-Term Enroute Coverage	High	Quantity of Pseudolites may not be Cost Effective
Interface		
Power	Med	Power Required Prior to Launch
RCVR Initiation	Low	Support A/C CDU
Irig Timing	Low	Needed for Post Processing
Velocity Measurement Accuracy	Low	Post Mission Accuracy is Met
Scoring (3 ft)	Low-Med	Optic System may be Needed
Output Power	Med-High	P-Code Transmission Requires 30 Watt ERP Would Depend on Range to Support Aircraft.

TABLE 11.3-9

GENERIC RANGE APPLICATIONS ISSUES

APPLICATION: LAND VEHICLES - DRONES

CONFIGURATION	ISSUE	RISK/ COMPLEXITY	COMMENTS
Low Dynamic Receiver - Land Vehicles	Size, Weight, Power	Low	Packaging Flexible, Vehicle Power Available.
	Masking	Med-High	Near Term Will Require Pseudolites. Terrain Dependent.
	Data Rate	Low	Rate of 1 or 2 per Second Adequate.



- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based on Consolidated Buy

Figure 11.4-1 Generic Airborne Systems OT&E/Training LCC Comparison

development, acquisition and O&M of GPS range equipments, including inverted range items, short-range translators, 5-channel receivers and pod sets for the test articles.

The all-non-GPS option costs are driven by the acquisition of user equipment transponders, the maintenance of tracking radars in the near and far term, and the acquisition and O&M

of three-phased array radars, four video theodolites and four laser radars for use in the far term.

The costs for the mixed option reflect lower acquisition costs, because GPS equipments are not procured until the far term, and higher O&M costs, because the non-GPS tracking radars are maintained through the near term.

The GPS options have a clear-cut cost advantage over the all-non-GPS option, as is shown in Fig. 11.4-1. This conclusion does not change when unit costs are submitted to reasonable sensitivity calculations.* Additionally, on this range, the commitment to GPS in the near term avoids approximately $10M of O&M for tracking radars which drive the mixed option costs over the all-GPS option costs.

11.5 GPS RANGE EFFECTIVENESS ANALYSIS

The GPS range effectiveness analysis was conducted in accordance with the methodology presented in Section 4.3. This section will summarize the effectiveness evaluation for the airborne weapon generic range.

The GPS composite range effectiveness screening summary for the Airborne Weapon Generic Range is presented in Table 11.5-1. This table illustrates the effectiveness of the near- and far-term GPS range options relative to the non-GPS options. This table shows that the majority of real-time and post-test accuracy requirements can be met by GPS receivers.

---

*Parameters varied included translator quantity and cost, transponder quantity, and phased array, tracking radar and pseudolite cost.

TABLE 11.5-1

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

Generic Range: Airborne Weapons (OT&E, Training)
Test Category: Aircraft, Drones, Missiles (A-A, A-S), Cruise Missiles OT&E; EW, Air Exercises and Training

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
Drivers:				
• Real-Time Accuracy	$\boxed{+}$	$\boxed{+}$	Aircraft, Cruise Missile	Better Terminal Position, Velocity
• Post-Test Accuracy	+	$\boxed{+}$	Aircraft, Drone (F)	"Z" Performance
• Broad Coverage	0	+	Cruise Missile	
• Low Altitude Coverage	+	+	All But A-S Players	
• Number of Players	$\boxed{+}$	$\boxed{+}$	Aircraft, Drone (F)	Receiver Equipped Player
• Data Rate	0	0	All	
Considerations:				
• Integration	0	+	Aircraft, Drones	No "Z" Aiding
• Technical Risk	$\boxed{-}$	$\boxed{-}$	Aircraft, Missile	Pod and Missile Antenna Issues
• Growth Potential	0	+	Drones	Tighter Formations
• Standardization	+	+	All	Single TSPI Source
• Portability	0	+	All	Reduced Resources
• Availability	+	+	All	
• Data Timeliness	+	+	Cruise Missile	Optics Processing for Velocity
GPS Applicability	High	High	Broad Applicability in Near and Far Term	

*GPS vs Non-GPS Options

Rating Key:
GPS Better +
GPS Same 0
GPS Worse -
Critical □

The critical items are in the area of translator applications with small missiles where GPS accuracies are marginal for tracking and cannot meet post-mission requirements with a C/A-code translator. Broad area coverage for the near term indicates both options are equivalent due to constraints imposed by data communications nodes. In the far term GPS can meet broad coverage requirements, however the primary limitations would be in the data communications area. GPS is rated better than non-GPS in low altitude coverage and capability to handle a number of player requirements. Both options are equivalent in data rate as GPS can meet the requirements.

For other considerations (such as integration) the options are considered equivalent in the near term as the installation of new system in either option is considered of equal difficulty. GPS receiver interfaces to processors and down link systems are as complex as current systems. One small advantage is that, in placing a GPS receiver in a multilateration system, the ranging functions of that system can be deleted, but the polling function must be retained. Integration in the far-term GPS option would be easier due to the availability of the satellite constellation, thus reducing the dependency on the pseudolites.

Technical risk is critical when considering application of translators or receivers in small missiles. The GPS equipment size, weight, and power constraints may preclude their use in small missiles.

GPS option growth potential in the near term is considered equivalent to the non-GPS due to the constraints imposed by pseudolites. These constraints are in the physical distribution on the ground and cost. In the far term GPS is better due to the availability of the satellite constellation

which offers unlimited player growth, which will only be constrained by the capacity of the data collection system.

The GPS option offers better equipment standardization than does the non-GPS option due to commonality in receivers in the family. In portability the options are considered equal in both near and far term, in that the GPS receiver, is a sensor within the system and any system can be made portable if required. There are slight advantages to a GPS system in that there would be less ground equipment to move, in some cases, i.e., less radars for tracking. Any system would require a protable data communications and processing system. Deployment of a GPS system might be faster than a non-GPS system, when survey requirements are considered as a GPS system could be self surveying, primarily in the far term.

Availability of both options is considered equal. This assessment is primarily based on the premise that a GPS receiver, as a sensor, will have a high realiability, but when place in a pod for example, will only be as reliable as the overall system which collects the data. Data timeliness could be increased, if GPS translators became practical, as this application would provide real-time data on missile tracking. If translators/receivers could satisfy scoring requirements, i.e., replace precision laser trackers and cinetheodolites, all data would be provided in a more timely fashion.

12. LAND-BASED WEAPONS GENERIC RANGE ANALYSIS

The Land-Based Weapon Generic Range used to support training and OT&E was modeled as a 25×25 km square in the near term and as a 50×50 km square in the far term. This range was based on three primary pattern ranges: TCATA, CDEC and NTC. Weapon categories using the range include short range missiles (A-to-A, A-to-S, and S-to-A), aircraft and drones. The range also supports exercises and training.

This chapter discusses generic range requirements in Section 12.1 The non-GPS range baseline is contained in Section 12.2 while the GPS scenario development is contained in Section 12.3. The latter describes the generic GPS ranges and the selected GPS TSPI configuration, and discusses GPS application issues. Life-cycle costs of the non-GPS and GPS generic range options are presented in Section 12.4 with the GPS range effectiveness analysis results presented in Section 12.5.

12.1 TSPI REQUIREMENTS ASSESSMENT

The TSPI requirements given in the data base for the primary and secondary candidate ranges were accumulated by test category for each of the test parameters. The compilation of these requirements and capabilities involved the use of engineering estimates for those cases where values were not provided by the individual range documentation. Table 12.1-1 illustrates a composite of the requirements for the range instrumentation by test parameter for all test categories in the Land-Based weapon generic range. This table reflects the range of values for each test category and test parameter.

TABLE 12.1-1
TSPI REQUIREMENTS

Generic Range: Land-Based Weapons									
TEST PARAMETER	A-A			A-S			S-A		EXERCISE & TRAINING
	LAUNCH A/C	Drone	Missile	LAUNCH A/C	Drone	Missile	Drone	Missile	
Real-Time Accuracy (1σ)									
Position (x,y),(z) ft	15	15	15	30	30	30	15	15	15-30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) fps	3	3	3	3	3	3	3	3	9
Timing (msec)	100	100	100	100	100	100	100	100	100
Data Rate (#/sec)	10	10	10	10	10	10	10	10	1-10
Post-Test Accuracy (1σ)									
Position (x,y),(z) ft	6-15	6-15	6-15	15	15	15	15	15	15-30
Velocity ($\dot{x}$,$\dot{y}$),($\dot{z}$) fps	3	3	3	3	3	3	3	3	9
Scoring Accuracy (ft-1σ Circ)	-	-	3	-	-	1-6	-	3	-
No. Test Articles	2-20	2-20	2-20	30	30	30	20-50	20-50	2000
Coverage Altitude - kft Distance - nm	0-10 50×50	0-10 50×50	0-10 50×50	0-10 50×50	0-10 50×50	0-10 50×50	0-50 50×50	0-50 50×50	0-10 50×50

12.2 GENERIC NON-GPS RANGE BASELINES

The non-GPS ranges were separated into near-term and far-term ranges. Near term covers the period 1985 through 1987, far term encompasses the period 1988 to 2004. These generic ranges were designed to handle the test categories using current instrumentation (near term) and projected range improvement instrumentation (far term). The instrumentation in non-specific and is represented by a type of TSPI instrumentation.

12.2.1 Instrumented Range Description

The non-GPS requirements for coverage provide the basis for range dimensions. The topography of the generic ranges could be described as having rolling terrain separated by valleys providing ground troop attack routes, surrounded by moderate hills providing low and high level air penetration routes, an area for live fire or ordnance, and an area for exercise/training and no-drop bomb scoring.

The test categories included in these ranges are air-to-air and air-to-surface testing, which includes the launch aircraft, target and missile (ordnance); and surface-to-air (target and ordnance). TSPI for unguided bombs was not considered in this analysis. The JT&E exercises and training test category includes the requirements for multiple aircraft and land vehicles TSPI.

Near-Term Non-GPS Range - Figure 12.2-1 illustrates the generic non-GPS range option for the near-term period. The range includes the type and quantities of TSPI instrumentation systems which would be required to handle the number of players specified for each type of test mission. The multilateration system is representative of a current TSPI system

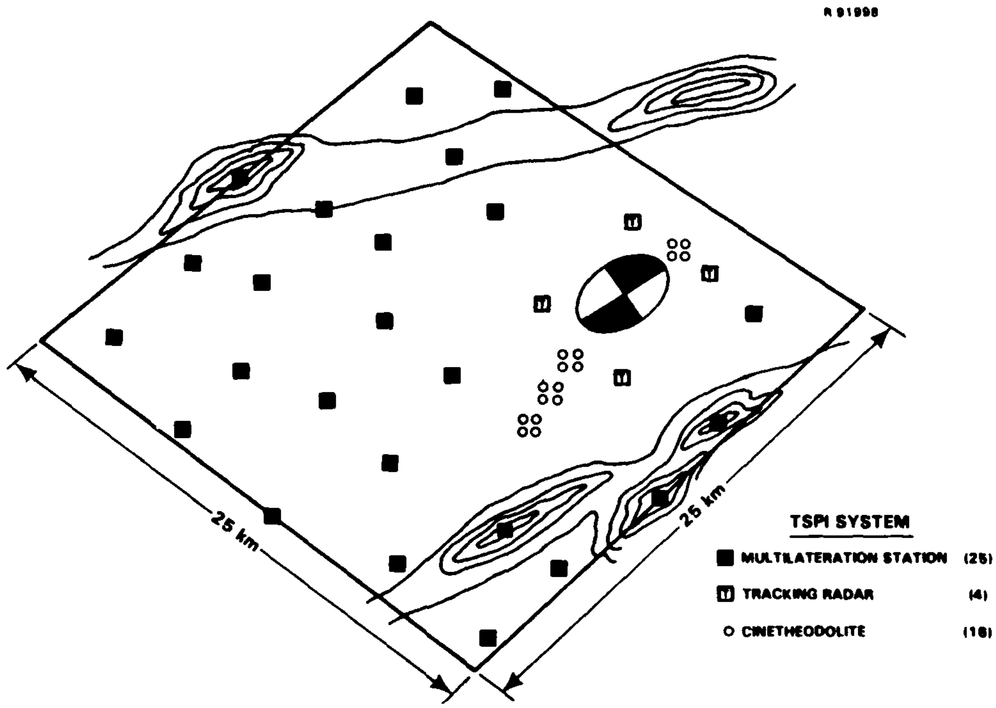


Figure 12.2-1 Generic Land-Based Weapons OT&E and Training Range: Near-Term Non-GPS Option

using remote stations. The radar and theodolite tracking systems represent both old and new technology and are serving a number of current ranges. Quantities of theodolites were estimated using a postulated number of simultaneous test articles to be tracked based on a 4 to 1 theodolite-to-player ratio.

This near-term non-GPS generic range was based upon an RMS-type range similar to TCATA with the added capability for A-A, A-S and S-A testing. The live fire area is depicted within the boundaries of the required area to accommodate the data communications system. It could, however, be placed outside the area for safety. The quantities of multilateration system were estimated using a typical A station matrix with a

station spacing of 5 km to cover a 25 x 25 km area from ground level to high altitude. (A list of instrumentation for this option is presented later in Table 12.3-3).

The baseline multilateration system shown in Fig. 12.2-1 utilizes 25 line-of-sight ground stations. As an alternative, the system could be implemented with a short-range groundwave system comparable to Loran. The latter would require 5-10 ground stations. A groundwave approach would minimize terrain masking problems, but at the cost of reduced accuracy, particularly for airborne users.

Far-Term Non-GPS Range - The far-term non-GPS range option is illustrated in Fig. 12.2-2. This range represents an upgrade of the near-term range to include extended coverage to meet coverage and number of participant requirements. The range consists of 50 multilateration stations distributed (depending on terrain) within the 50 x 50 km required area. The range also contains tracking radars and cinetheodolites in sufficient quantities to handle A-A, A-S, and S-A precision testing requirements for OT&E. The groundwave option is also applicable in this time frame, but would require approximately 20 ground stations because of command and control LOS considerations.

12.2.2 Non-GPS Range Capabilities

The near- and far-term non-GPS capabilities are condensed in Tables 12.2-1 and 12.2-2. One of the test categories for which these are no near-term capabilities given is air-to-air testing. This requirement has recently developed. The table indicates the absence of this capability by a "0" in the near-term column while the far-term requirement for this test category is 15 feet (x,y) and 15 feet (z). The capability to

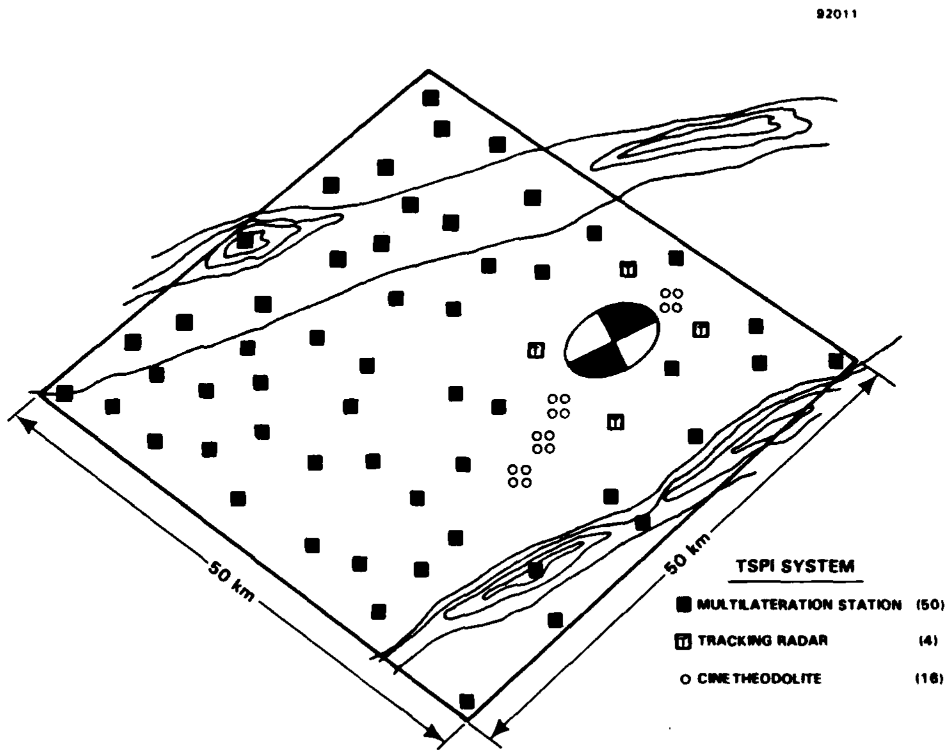


Figure 12.2-2 Generic Land-Based Weapons OT&E and Training Range: Far-Term Non-GPS Option

satisfy this requirement could be accomplished by tracking radars/cinetheodolites. This requirement for the large number of players (2000) was derived from OT&E field tests of the M-on-N variety.

12.3 GPS SCENARIO DEVELOPMENT

The non-GPS requirements and capabilities provide the basis for comparison with GPS receiver and translator capabilities for GPS scenario development. The test requirements for the non-GPS test categories are compared to the GPS capability for satisfying the test requirements. The primary test parameter drivers compared are real-time accuracy, data rate, post-mission accuracy, scoring accuracy, number of test articles and

TABLE 12.2-1

NEAR-TERM NON-GPS CAPABILITIES

GENERIC RANGE: LAND-BASED WEAPONS (TRAINING, OT&E)

TEST PARAMETER	A-A			A-S			S-A		EXERCISE & TRAINING
	LAUNCH A/C	Drone	Missile	LAUNCH A/C	Drone	Missile	Drone	Missile	
Real-Time Accuracy (1σ)									
Position (x,y),(z) ft	0	0	0	9-15	9-15	9-15	9-15	9-15	25-75
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	0	0	0	0.1-3	0.1-3	0.1-3	0.1-9	0.1-9	3
Timing (msec)	0	0	0	100	100	100	100	100	100
Data Rate (#/sec)	0	0	0	10-20	10-20	10-20	10-20	10-20	1-10
Post-Test Accuracy (1σ)									
Position (x,y),(z) ft	0	0	0	9-15	9-15	9-15	9-15	9-15	<25-75
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	0	0	0	0.1-3	0.1-3	0.1-3	0.1-9	0.1-9	3
Scoring Accuracy (ft-1σ Circ)	0	0	0	-	-	3	-	3	-
No. Test Articles	0	0	0	1-6	1-6	1-6	1-6	1-6	200
Coverage									
Altitude - kft	0	0	0	0-10	0-10	0-10	0-50	0-50	0-10
Distance - km	0	0	0	25×25	25×25	25×25	50×50	50×50	25×25

TABLE 12.2-2

FAR-TERM NON-GPS CAPABILITIES

GENERIC RANGE: LAND-BASED WEAPONS (TRAINING, OT&E)

TEST PARAMETER	A-A			A-S			S-A		EXERCISE & TRAINING
	LAUNCH A/C	Drone	Missile	LAUNCH A/C	Drone	Missile	Drone	Missile	
Real-Time Accuracy (1σ)									
Position (x,y),(z) ft	9-15	9-15	9-15	9-15	9-15	9-15	9-15	9-15	25-75
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	3
Timing (msec)	100	100	100	100	100	100	100	100	100
Data Rate (#/sec)	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	1-10
Post-Test Accuracy (1σ)									
Position (x,y),(z) ft	9-15	9-15	1-3	9-15	9-15	1-3	9-15	1-3	25-75
Velocity $(\dot{x},\dot{y}),(\dot{z})$ fps	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	0.1-3	3
Scoring Accuracy ($ft-1\sigma$ Circ)	-	-	3	-	-	3	-	3	-
Number of Test Articles	1-6	1-6	1-6	1-6	1-6	1-6	1-6	1-6	500-2000
Coverage									
Altitude - kft	0-10	0-10	0-10	0-10	0-10	0-10	0-50	0-50	0-10
Distance - km	50×50	50×50	50×50	50×50	50×50	50×50	50×50	50×50	50×50

coverage in altitude and distance (volume). Other GPS receiver/translator considerations are equipment size, weight and power capacity, which provide estimates of whether or not the GPS equipment can be used to provide the required TSPI data. The performance trade-offs and the size, weight and power projections contained in Section 3 provide a basis for the GPS scenario development.

12.3.1 Instrumented GPS Range Description

This section contains the development of the generic GPS ranges for the Land-Based Weapons Range in the near- and far-term periods.

Requirements vs GPS capabilities - The near- and far-term GPS capabilities are compared to TSPI requirements in Table 12.3-1. The GPS receiver/trans capabilities are illustrated by C/A- and P-code for non-differential and differential modes of operation. A P-code receiver used in the differential mode provides the best accuracy and will satisfy most requirements. It comes close to satisfying any currently specified real-time or post-mission scoring requirements.

In order to illustrate which receiver, C/A- or P-code, would satisfy most of the generic range requirements a distribution of requirements containing both real-time and post-test accuracies was derived. This distribution contained the requirements from all test categories. This distribution was compared to the real-time and post-mission accuracies (estimated) for non-differential and differential C/A- and P-code to illustrate the percentage of the requirements that would be satisifed by a C/A- or P-code receiver. This comparison is presented in Table 12.3-2. The table illustrates, for example, that a P-code receiver in real-time differential mode would satisfy

TABLE 12.3-1

REQUIREMENTS VS GPS CAPABILITIES*

Generic Range: Land-Based Weapons
Generic Test Category: All

TEST PARAMETER	TSPI REQUIREMENT*	NEAR- & FAR-TERM GPS CAPABILITIES			
		NON-DIFFERENTIAL		DIFFERENTIAL	
		C/A	P	C/A	P
• Real-Time Accuracy - (1σ)					
Position (x,y),(z) - ft	15-30,15-30	30,51	14,23	25,41	7,21
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	3-9,3-9	0.06-0.65, 0.11-1.10			
Timing (msec)	100	100			
• Date Rate (#/sec)	1-10	1-20			
• Post-Mission Accuracy - (1σ)					
Position (x,y),(z) - ft	6-30,6-30	18,30	9,14	6,10	2,4
Velocity $(\dot{x},\dot{y}),(\dot{z})$ - fps	3-9,3-9	0.02, 0.03			
• Scoring Accuracy (ft-1σ Circ)	3	N/A	N/A	N/A	N/A
• Number of Test Articles	2-2000	6[1]-2000[2]	2000[2]	6[1]-2000[2]	2000[2]
• Coverage					
Altitude - kft	0-50	0-50+			
Distance - km	50×50	50×50+			

[1]Estimated limits of number of translators

[2]Receiver Quantities

*Parameter ranges, reflects differing requirements for Test Categories

86 percent of the requirements (ranging from 10 ft and up) and a C/A-code receiver in real-time differential mode would satisfy 69.7 percent of the requirements (25 ft and up). If for example, a range has a 25 ft real-time and a 2 ft post-mission accuracy requirement, the requirement could be satisfied by a P-code receiver in the differential mode to satisfy both requirements.

TABLE 12.3-2
REQUIREMENTS VS GPS
(C/A- AND P-CODE) CAPABILITIES

ACCURACY REQUIREMENTS (ft)	% OF TOTAL	REAL-TIME ACCURACY CAPABILITY (ft)				POST-MISSION ACCURACY CAPABILITY (ft)			
		NON-DIFFERENTIAL		DIFFERENTIAL		NON-DIFFERENTIAL		DIFFERENTIAL	
		C/A	P	C/A	P	C/A	P	C/A	P
150+	13.9	30,51*	14,23*	25,41*	7,12*	18,30*	9,14*	6,10*	2,4*
50	20.9								
30	6.9	41.8%							
25	27.9			69.7%		69.7%			
20	2.3		72.1%				72.1%		
10	13.9				86.0%			86.0%	
5	9.3								
2	2.3								97.6%
0.5	2.3								

*Estimated GPS accuracies for uncompensated user dynamics.

Near-Term GPS Option - The near-term GPS range option is illustrated in Fig. 12.3-1. Thi range employs pseudolites in an inverted range configuration to provide signals to the receivers because a sufficient satellite constellation will not be available until late in 1987. The pseudolites would also be available to be used with the full satellite constellation 1988-2005 to support GPS operations in the presence of ECM, and to provide signal continuity during satellite signal outages due to masking. The range contains sufficient non-GPS instrumentation to satisfy missile tracking requirements which are not currently satisfied by expendable translators due to number of players, missile space, weight and power constraints.

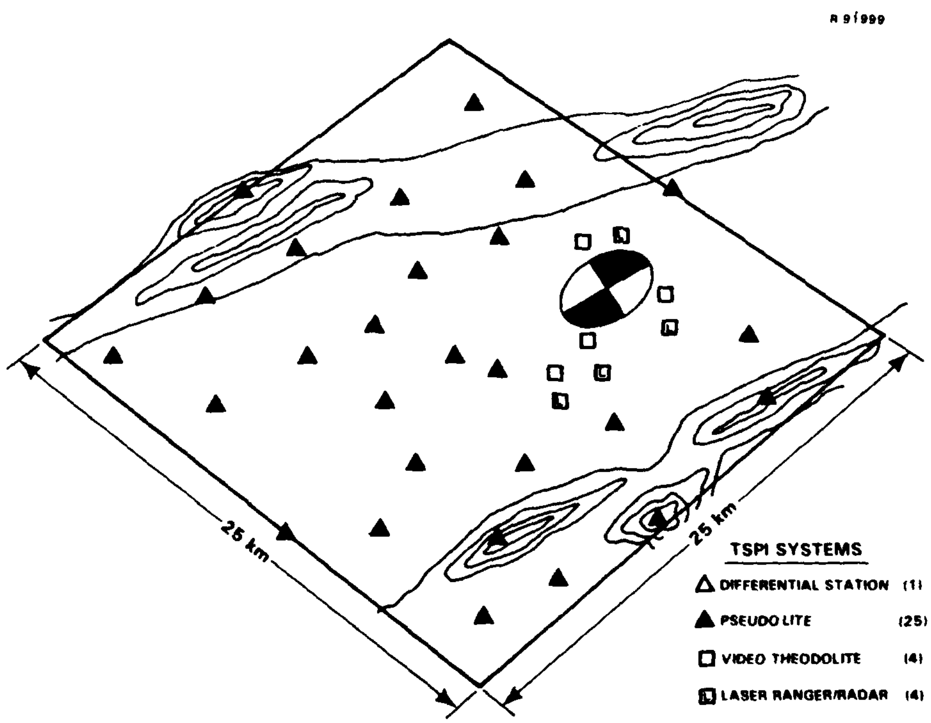


Figure 12.3-1 Generic Land-Based Weapons OT&E and Training Range: Near-Term GPS Option

The range also has a data communication subsystem in the form of telemetry/C^2 data link stations. These stations will transmit and receive data from aircraft pods containing GPS receivers. The number of these stations has been reduced since the multilateration function of the station is no longer required in the GPS option. These stations would be placed within the range to optimize the reception of data down-linked from aircraft, personnel, and vehicles.

Personnel, crew-served weapons and vehicles (tanks, APC, etc) would use a 1 or 2 channel P-code receiver without aiding. Helicopters and close air support aircraft would use a multi-channel P-code receiver with a 3rd-order carrier loop or IMU aiding. High speed support aircraft would use a pod-mounted 5 channel P-code receiver with a 3rd-order carrier loop or IMU aiding. These receivers would also be used in the far-term option. Vehicle drones would use the 1 or 2 channel P-code receiver and high dynamic drone aircraft would use an internally-mounted 5 channel P-code receiver. Both GPS options would contain a differential receiver.

Both ranges have an Inverted Range Control Center (IRCC) to control the pseudolites and a timing receiver is included to provide timing for the inverted range. The near-term GPS option includes an inverted range, which is the equivalent of a ground-based satellite system. The ground based pseudolites would provide continuous L_1 signals to the receivers during the period where there is not continuous overhead satellite coverage. A listing of equipments for the near- and far-term GPS options is presented in Table 12.3-3.

<u>Far-term GPS Option</u> - The far-term GPS range option is illustrated in Fig. 12.3-2. This range features an expanded area and uses the satellite constellation supplemented by

TABLE 12.3-3

INSTRUMENTATION OPTIONS COMPARISON - LAND-BASED WEAPONS

NEAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	25	GPS Equipment		
TLM/C² Data Link	10	---	Differential Station	1	---
Tracking Radar			Geoceiver	1	---
Dish	---	4	Timing Receiver	1	---
Laser Ranger/Radar	4	---	Translator Receiver	6	---
Video Theodolite	4	---	Pseudolite	25	---
Digital Cinetheodolite	---	16	Test Article Equipment	YES	YES
			Surveillance Radar	1	1

FAR-TERM INSTRUMENTATION

INSTRUMENTATION	OPTION		INSTRUMENTATION	OPTION	
	GPS	NON-GPS		GPS	NON-GPS
Multilateration Station	---	50	GPS Equipment		
TLM/C² Data Link	20	---	Differential Station	1	---
Tracking Radar			Geoceiver	1	---
Dish	---	4	Timing Receiver	1	---
Laser Ranger/Radar	4	---	Translator Receiver	8	---
Video Theodolite	4	---	Pseudolite	12	---
Digital Cinetheodolite	---	16	Test Article Equipment	YES	YES
			Surveillance Radar	1	1

pseudolites on the ground. The range uses a differential receiver station to obtain the best accuracy from the GPS receivers. This range also contains non-GPS missile tracking instrumentation to fulfill those precision requirements which may not be satisfied by the GPS translator.

The range also has a data communications subsystem in the form of telemetry/C^2 data link stations which would transmit and receive data from the players and from the central processing and control center. As in the near-term option,

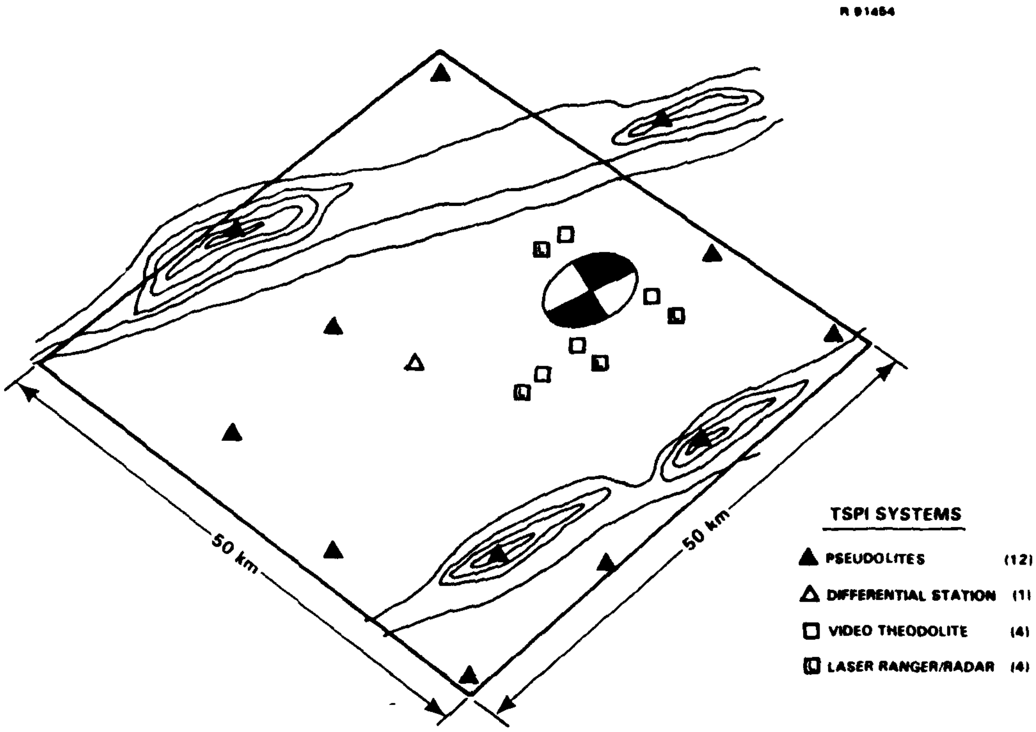


Figure 12.3-2 Generic Land-Based Weapons OT&E and Training Range: Far-Term GPS Option

the number of these stations has been reduced since the multilateration function would no longer be required. The types of receivers to be used on this option are the same as those indicated in the near-term option.

Range Instrumentation Options - The land-based generic range near- and far-term instrumentation options for both non-GPS and GPS are presented in Table 12.3-3. This table presents the estimated quantities of instrumentation which would be contained in each generic range option. This data is used as the basis for life-cycle costing discussed in Section 11.4.

12.3.2 GPS Range Configuration

Each test vehicle is configured with a GPS complement of equipment, which (in most cases) meets the TSPI accuracy requirements. The configurations are identical to those described in 11.3.2, and are not discussed here. A summary of the near- and far-term GPS configurations and the receiver/translator requirements by test category is presented in Table 12.3-4.

TABLE 12.3-4
COMPARISON OF GPS SUPPORT SCENARIOS
AND TSPI REQUIREMENTS

LAND-BASED WEAPONS GENERIC RANGE

RANGE TSPI REQUIREMENT	CONFIGURATIONS*	
	NEAR TERM	FAR TERM
Launch Aircraft	1,2	1,2
Target	1,2,3	1,2,3
Ordnance	3	3
Exercise JT&E	1,2	1,2

*Numbers correspond to configurations in Section 3.4.

12.3.3 GPS Application Issues

This section addresses the risk and/or complexity of various issues which have been identified in the application of GPS instrumentation to the land-based generic range. The risk and/or complexity of these issues has been subjectively rated as low, medium or high. Low has little or no risk/complexity; medium has a moderate risk/complexity which could

affect the application, but has workable solution; and high may severely impact the application and render it not usable. The applications addressed include aircraft, missiles (ordnance), drone aircraft, and land vehicles and personnel.

Aircraft, Medium and High Dynamic Receiver - The aircraft medium and high dynamic (onboard) receiver issues are presented in Table 12.3-5. The majority of issues are rated low to medium. Tactical navigation receiver is rated high due to service-dependent aircraft modification requirements. The use of a tactical GPS receiver interfaced with a pod will most likely not be allowed in certain aircraft. These aircraft can, however, use a pod-mounted GPS receiver.

Aircraft, High Dynamic Pod Receiver - The aircraft high dynamic pod receiver issues are presented in Table 12.3-5. The majority of issues are rated low to medium. The accessability of an aircraft 1553 bus, to include the tactical GPS receiver data will most likely not be allowed due to restrictions on aircraft modifications applicable to operational service aircraft. These aircraft may, however, be fitted with a pod-mounted high dynamic receiver.

Missile, High Dynamic Translator - These issues are presented in Table 12.3-6. The risk and complexity of installing a translator in a small missile airframe is rated as high and the use of a translator will be dependent upon the translator trade-offs discussed in Section 3. If used, a translator will be applied to ranges where the number of players will be limited (6 or less) and accuracy capabilities of the translator system will be sufficient for all specified requirements.

Drone, Aircraft High Dynamic Receiver - The drone aircraft high dynamic receiver issues have been rated low to medium.

TABLE 12.3-5

GENERIC RANGE APPLICATION ISSUES

APPLICATION: AIRCRAFT

CONFIGURATION	ISSUE	RISK/COMPLEXITY	COMMENTS
Medium and High Dynamic Reciver	Tactical Nav Receiver Accessibility	Low-High	Service Dependent
	TSPI Receiver Size	Low-Med	Aircraft Dependent
	TSPI Receiver Weight, Power	Low	Aircraft Power Available
	Antenna Masking, ECM Operation	Med	Use Stripline Antenna
			INS & GT May Allow Operations in ECM With FPRA
	TSPI Data Rate	Low-Med	Software Mods for IP may be Required if JPO Receiver
	Cost	Low	JPO P-Code Development Baseline
High Dynamic Pod Receiver	Tactical Nav Receiver, 1553 Accessibility	Low-High	Service and Aircraft Dependent
	TSPI Receiver Size	Med	Must Fit Aim-9 Pod
	TSPI Receiver Weight, Power	Low	Aircraft Power Available
	Antenna Masking, ECM Operation	Med	Same as Above. Can also use Pod Extension to Ease Masking
	Store Station Communications	Low-Med	Data Bus Availability Dependent
	Pod Commonality	Med	Common Receivers Possible, Pod will be Unique to Range Common System & Data Requirements
	TSPI Data Rate	Med	Must Interface With Existing Pod Communications Systems

TABLE 12.3-6

GENERIC RANGE APPLICATION ISSUES

APPLICATION: MISSILES

CONFIGURATION	ISSUE	RISK/ COMPLEXITY	COMMENTS
High Dynamic Translator (C/A-Code) Small Missiles	Power	High (Low-Med)	Missile Dependent, Will Need Batteries
	Size	Med-High (Low-Med)	Missile Dependent-Space Available
	Weight	Low-Med	Missile Dependent
	IMU Size, Weight, & Power	High	Missile Dependent
	Antenna Coverage	Low-Med	TWA in Development
	Real Time IMU Aiding	High	Requires Synchronization With GPS Data
	Bandwidth	High	1-2 Missiles With P-Code; 4-6 With C/A
	Accuracy	Low (High)	C/A Code Estimated Accuracy Does Not Meet Requirements/Capabilities

Current receiver designs will have to be reduced in size to fit the family of drone vehicles, and will most likely not be available for near term applications. These issues are presented in Table 12.3-7.

Drone, Aircraft High Dynamic Translator - The issues related to a high dynamic translator application to a drone aircraft are presented in Table 12.3-7 and are rated low to high depending on the code used in the translator. The translator performance trade-offs discussed in Section 3 will have to be considered for translator application in drone aircraft.

Land Vehicle and Personnel Low Dynamic Receiver - The issues relating to land vehicle and personnel low dynamic receiver are presented in Table 12.3-8. The only issue which was rated as possibly high is terrain masking in the near-term application using pseudolites. This risk is generally terrain-dependent for any specific range and a cost factor to consider. In the far-term period, the risk should be reduced to low with the use of a full constellation of satellites.

12.4 LIFE-CYCLE COST COMPARISON

For the Generic Land OT&E/Training range, the differential 20-year life-cycle cost comparison of the all-GPS option versus a option and the near-term non-GPS/far-term GPS option (mixed option) is shown in Fig. 12.4-1. Figure 12.4-1 is based on the alternative non-GPS option discussed in Section 12.2, which utilizes groundwave-based hyperbolic multilateration rather than RMS-type line-of-sight system. The major contributors to cost in the all-GPS option are the development, acquisition and O&M of GPS range equipmnts, including inverted range items, short-range translators and 1-channel receivers for the

TABLE 12.3-7
GENERIC RANGE APPLICATION ISSUES
APPLICATION: DRONES

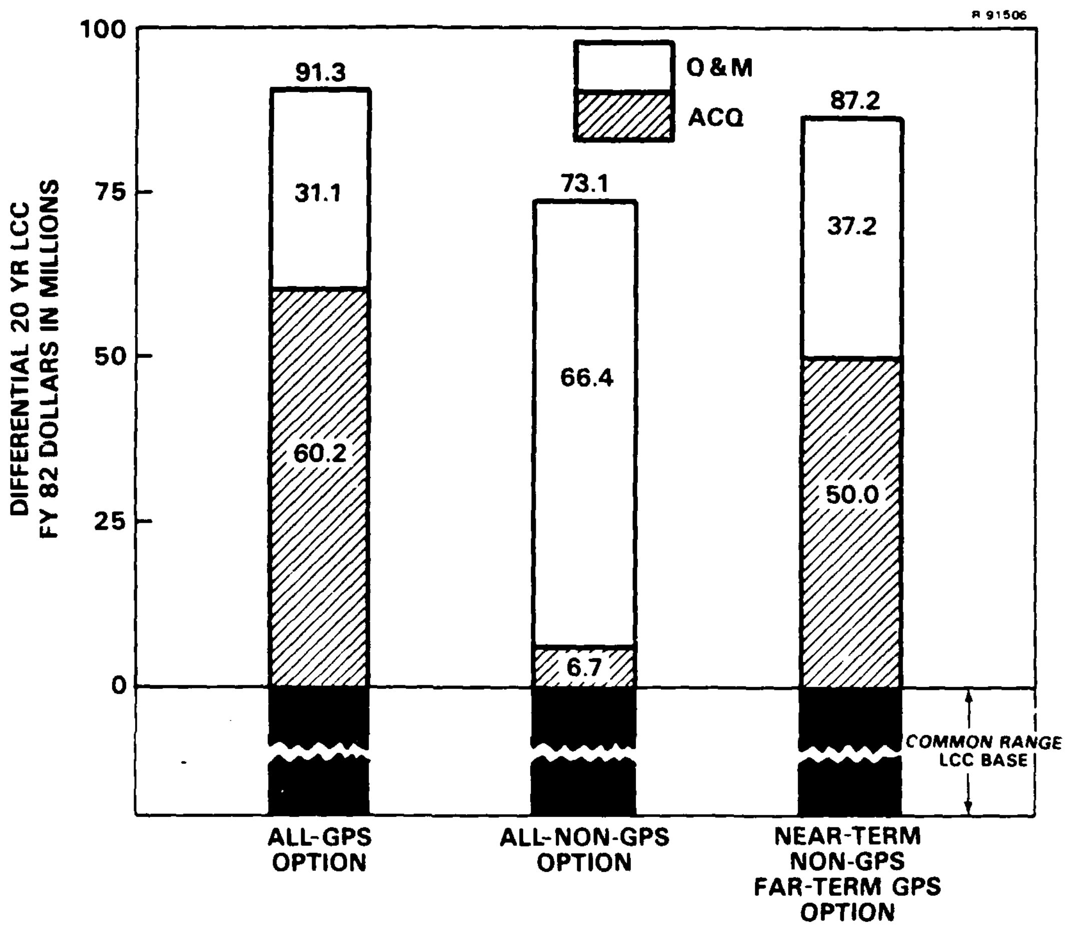
CONFIGURATION	ISSUE	RISK/COMPLEXITY	COMMENTS
High Dynamic Receiver	Size	Low-Med	Vehicle Dependent
	Weight and Power	Low	Drone Power Probably Adequate
	Antenna Masking, ECM Operation	Med	Same as for Aircraft Receiver Option
	Initialization	Low	Mother-Daughter Interface Required for "M Set" Option
	Cost	Low-Med	Limited "M Set" Development Baseline
	TSPI Data Rates	Low-Med	Low Data Rates from "M Set"
High Dynamic Translator P-Code (C/A-Code)	Power	Low-Med (Low)	Vehicle Dependent
	Size and Weight	Low-Med	Vehicle Dependent
	IMU Size, Weight, Power	Low-Med	Vehicle Dependent
	Antenna Masking, ECM Operation	Med	Same as for Aircraft*
	Real-Time IMU Aiding	High	GPS/IMU Data Synchronization
	Cost	Med-High (Low)	New Development for P-Code Translator and Translater Receiver (C/A-Code Being Developed)
	Signal Bandwidth	High	May Limit Use to 1 or 2 Vehicles (4-6 Vehicles)

TABLE 12.3-8

GENERIC RANGE APPLICATIONS ISSUES

APPLICATION: LAND VEHICLES AND PERSONNEL (MANPACK)

CONFIGURATION	ISSUE	RISK/ COMPLEXITY	COMMENTS
Low Dynamic Receiver - Land Vehicles	Size, Weight, Power	Low	Packaging Flexible, Vehicle Power Available.
	Masking	Med-High	Near Term Will Require P-SATs. Terrain Dependent.
	Data Rate	Low	Rate of 1 or 2 per Second Adequate
Low Dynamic Receiver Personnel Mainpack	Size, Weight, Power	Low	Within State-of-the-HRT, will Require Batteries.
	Masking	Med-High	Near Term may require many P-SATs Terrain Dependent.
	Data Rate	Low	Rate adequate.



- Prorated GPS Equipment Development Cost
- GPS Equipment Unit Cost Based on Consolidated Buy

Figure 12.4-1 Generic Land-Based Weapons Range LCC Comparison

test articles. Of particular note is the fact that this range bears the entire $10M burden for 1 or 2 channel receiver development, as it is the only user of that item.

The all non-GPS groundwave option costs are driven by the acquisition of user equipment transponders, and the O&M of 16 cinetheodolites and four tracking radars retained

through the far term. The mixed cost option costs reflect lower acquisition costs, because GPS equipments are not procured and maintained until the far term, and high O&M costs, because the non-GPS cinetheodolites and tracking radars are maintained through the near term.

Figure 12.4-1 indicates that the non-GPS groundwave option in this case is the lowest cost option. However, if non-GPS costs are understated by 25% and GPS costs are overstated by 25%, the conclusion is reversed.* Furthermore, the difference between the all-GPS option and the mixed option is so small that those two must be considered essentially equal. There appears to be a cost advantage to the non-GPS groundwave option, but the choice is not clean-cut.

The baseline non-GPS option defined in Section 2.2 would exploit RMS technology to provide better accuracy for airborne users than the groundwave option, but at a higher cost. The acquisition and O&M costs associated with the additional ground stations and supporting systems would raise the non-GPS system life-cycle costs to $113M, even without assuming higher user equipment costs. Thus, even for reasonable cost excursions, either GPS option would be less expensive than the baseline (RMS-type) non-GPS option.

12.5 GPS RANGE EFFECTIVENESS ANALYSIS

The GPS range effectiveness analysis was conducted in accordance with the methodology presented in Section 4.3. This section summarizes the effectiveness evaluation for the Land-Based Weapon Generic Range.

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*Other sensitivity analyses, performed by varying translator quantity to maximum and minimum values respectively widen and narrow the gap between GPS-based and non-GPS based options costs.

The GPS composite range effectiveness screening summary for the Land-Based Weapon generic range is illustrated in Table 12.5-1. Overall, both the near-term and far-term GPS options are rated high. The negative ratings which are also considered critical come from the application of translators to the ordnance (small missile) test category. These negative aspects may be overcome in time by the use of all-digital receivers.

The table shows that the majority of real-time and post-test accuracy requirements can be met by GPS receivers. The critical items are in the area of translator applications with small missiles where GPS accuracies are marginal for tracking and cannot meet post-mission requirements with a C/A-code translator. Broad area coverage for the near term indicates both options are equivalent due to constraints imposed by data communications modes. In the far term, GPS can meet broad coverage requirements; however, the primary limitations would be in the data communications area. GPS is rated better than non-GPS in low altitude coverage and capability to handle player requirements. Both options are equivalent in data rate as GPS can meet the requirements.

For other considerations such as integration, the options are considered equivalent in the near term as the installation of a new system in either option is considered of equal difficulty. GPS receiver interfaces to processors and down-link systems are as complex as current systems. One small advantage is that in placing a GPS receiver in a multilateration system, the ranging functions for that system can be deleted, but the polling function must be retained. Integration in the far term GPS option would be easier due to the availability of the satellite constellation, thus reducing the dependecy on the pseudolites.

TABLE 12.5-1

GPS COMPOSITE RANGE EFFECTIVENESS SCREENING

Generic Range: Land-Based Weapons (OT&E, Training)
Test Category: Aircraft, Drones, Missiles (A-A, A-S, S-A), Land Vehicles, Troops

MEASURES-OF-MERIT*	GPS RELATIVE ADVANTAGE*		PACING REQUIREMENTS	COMMENTS/RESTRICTIONS
	NEAR TERM	FAR TERM		
Drivers:				
• Real-Time Accuracy	+, $\boxed{-}$	+, $\boxed{-}$	Aircraft and Exercises, Missiles	"Z" Accuracy, C/A Translator
• Post-Test Accuracy	$\boxed{+}$	$\boxed{+}$	All A-A Players (N), Exercises	No N.T. A-A Capability
• Broad Coverage	+	0	All A-A Players (N)	No N.T. A-A Capablity
• Low Altitude Coverage	+	0	All A-A Players (N)	No N.T. A-A Capablity
• Number of Players	$\boxed{+}$	$\boxed{+}$	Aircraft, Drones (F)	
• Data Rate	+, -	+, -	All A-A Players, Exercises	2 Channel Receivers
Considerations:				
• Integration	0	0		
• Technical Risk	$\boxed{-}$	$\boxed{-}$	Aircraft, Missile	Pod and Missile Antenna Issues
• Growth Potential	0	0		
• Standardization	0	0		
• Portability	0	0		
• Availability	+	0	A-A Players	
• Data Timeliness	0	0		
GPS Applicability	High	High	Post-Test Accuracy and Number of Players	

*GPS vs Non-GPS Option

Rating Key:
GPS Better +
GPS Same 0
GPS Worse -
Critical □

Technical risk is critical when considering application of translators or receivers in small missiles. The GPS equipment size, weight, and power constraints may preclude their use in small missiles.

GPS option growth potential in the near term is considered equivalent to the non-GPS option due to the constraints imposed by pseudolites. These constraints are in the physical distribution on the ground and cost. In the far term, GPS is better due to the availability of the satellite constellation which offers unlimited player growth and will only be constrained by the capacity of the data collection system.

The GPS option offers better equipment standardization than does the non-GPS option due to commonality in receivers in the family. In portability, the options are considered equal in both near and far term in that the GPS receiver is a sensor within the system and any system can be made portable if required. There are slight advantages to a GPS system in that there would be less ground equipment to move, but any system would require a portable data communications and processing system. Deployment of a GPS system might be faster than a non-GPS system when survey requirements are considered, as a GPS system could be made to be self surveying in the far term.

Availability of both options is considered equal. This assessment is primarily based on the premise that a GPS receiver, as a sensor, will have a high reliability, but when placed in a pod for example, will only be as reliable as the overall system which collects the data. Data timeliness could be increased, if GPS translators became practical, as this application would provide real-time data on missile tracking. If translators/receivers could satisfy scoring requirements, i.e., replace precision laser trackers and cinetheodolites, all data would be provided in a more timely fashion.

13. RECOMMENDED GPS EQUIPMENT DEVELOPMENT

The GPS Cost Benefit assessment documented in the previous chapters demonstrated the potential of GPS-based range instrumentation to provide cost-effective support for Tri-Service test and training. For most generic ranges, GPS offered either lower cost, higher effectiveness, or both (see Table 13-1). In general, GPS offers the test range community unique capabilities with respect to a combination of accuracy and coverage, the latter being particularly true in the far term with an operational 18 satellite constellation. This chapter is devoted to GPS equipment development recommendations (Sections 13.1 and 13.2) and a summary of GPS implementation issues (Section 13.3).

13.1 GPS USER EQUIPMENT

The recommended family of GPS user equipment includes both receivers and translators which will serve as sources of test article TSPI data. These equipments must be capable of operating in dynamic environments ranging from that encountered in strategic or tactical missiles and fighter aircraft down to land vehicles and personnel. In addition, TSPI data from these test articles must be transmitted to control centers at ranges varying from hundreds of miles down to a few miles. Because of this diversity in operating requirements, two classes of test article receivers and translators are specified: Full and Basic Capability Receivers and Low and High Power Translators. Features of these equipments are described in the following subsection. (See Table 13.1-1 for a tabulation of some of the top-level design parameters.)

TABLE 13-1
COST EFFECTIVENESS (NEAR/FAR TERM)

GENERIC RANGE	LOWEST COST	GPS EFFECTIVENESS	PREFERRED IMPLEMENTATION
Long-Range	GPS/GPS	High/High	GPS/GPS
Extended-Range	GPS/GPS	High/High	GPS/GPS
Short-Range (Land)	Non-GPS/GPS	Moderate/High	Non-GPS/GPS
Short-Range (Water)	Non-GPS/GPS	Moderate/High	Non-GPS/GPS
Airborne	GPS/GPS	High/High	GPS/GPS
Land-Based	Non-GPS/Non-GPS	High/High	Non-GPS/GPS*
Sea-Based (Fixed) Over-Land At-Sea	Non-GPS/GPS	Low/Moderate -/High	Non-GPS/GPS
Sea-Based (Moving) W/O OTH Targeting OTH Targeting	-/Non-GPS	-/Moderate -/High	-/GPS†

*GPS is effective but costly option

†Adjunct to baseline system to exploit GPS world-wide common grid

13.1.1 Receiver Characteristics

The 5-channel Full Capability Receiver (see Table 13.1-1) should be optimized to provide maximum performance (accuracy, data rate, etc.) in high and medium dynamic applications. P-code tracking on the L_1 and L_2 frequencies is specified to provide precise TSPI data which can be corrected for ionospheric refraction if desired. However, the receiver design should be sufficiently modular to readily produce a C/A-code, L_1 frequency-only receiver for applications where less stringent accuracies are required. The fifth channel, normally used for L_2 frequency tracking, is useful to both

TABLE 13.1-1

PRELIMINARY GPS USER EQUIPMENT PARAMETERS*

PARAMETERS	RECEIVERS		TRANSLATORS	
	FULL** CAPABILITY	BASIC CAPABILITY	LOW POWER	HIGH POWER
Channels	5	2(1)	-	-
Codes	P, C/A	P, C/A	C/A	C/A
Frequency	L_1†, L_2	L_1	L_1	L_1
Size (in^3)	<600††	<450††	<30	<140
Weight (lb)	<40	<25	<3	<10
Power (W)	<140	<100	<45	<100

*1985 Projections.

**Two packaging options: rack-compatible and pod-mounted.

†Translator signal receiver will have common components except for an RF Down Link front-end module.

††Includes removable data processor module.

the P- and C/A-code configurations for tracking a fifth satellite to shorten outages during "new" satellite selection.

The receiver should be capable of accepting auxilliary inputs such as IMU or altimeter data for providing higher data rates and shorter signal acquisition/reacquisition times. It should also be capable of accepting direct inertial aiding of the receiver tracking loops to improve tolerance to vehicle dynamics, EM interference, and signal fading due to non-isotropic antenna performance.

Some other desirable operating capabilities which should be incorporated into the design are listed below:

- Accept ρ, $\dot{\rho}$* corrections and satellite designations from differential ground stations
- Output ρ, $\dot{\rho}$ to telemetry interface or x, y, z, t to data processor
- Output TSPI data with fewer than four signal sources utilizing internal clock and/or "z" aiding signals
- Produce data rates of 10 Hz without and 20 Hz with IMU aiding
- Accomodate pseudolites.

As indicated, the Full Capability Receiver should be available in both rack-compatible and pod-mounted options.

The <u>Basic Capability Receiver</u> is the result of compromises to reduce size and cost at the expense of some performance capability reduction and is intended for use in low or medium dynamic applications. Two channels are specified to halve the normal reacquisition time of a one channel set (45 sec) when outages occur and permit non-disruptive selection of "new" satellites†. In areas of input and output flexibility, the Basic Capability Receiver shows many of the features of its counterpart. It does not accomodate direct inertial aiding of the receiver tracking loops, although it can accept auxiliary TSPI inputs such as IMU or altimeter data. It also cannot make dual-frequency ionospheric corrections and will only produce data rates up to 1 Hz without external velocity inputs.

In order to enhance commonality, modular designs are recommended. An example of some major functions which should

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*Pseudo-range and delta range measured by the receiver for for each satellite.

†A single channel option could be selected if these shortcomings are acceptable.

be modularized is shown in Fig. 13.1-1. In this figure, six blocks have been identified as common modules for both the Full and Basic Capability Receivers. The L_1 front-end, although common to both receivers, should be replacable by an S-band module in the Full Capability Receiver for translator signal tracking. Also, the modular data processor (which may be a "bolt-on" addition to the receiver package) can be deleted to reduce size where outputs in terms of ρ and $\dot{\rho}$ are acceptable. Finally, the antenna may be a common module in limited high and medium dynamic applications where pods are employed or operational antennas are used. To accomodate the use of pods, both pod-mounted and conformal wing-mounted antenna designs which can interface with either receiver should be developed.

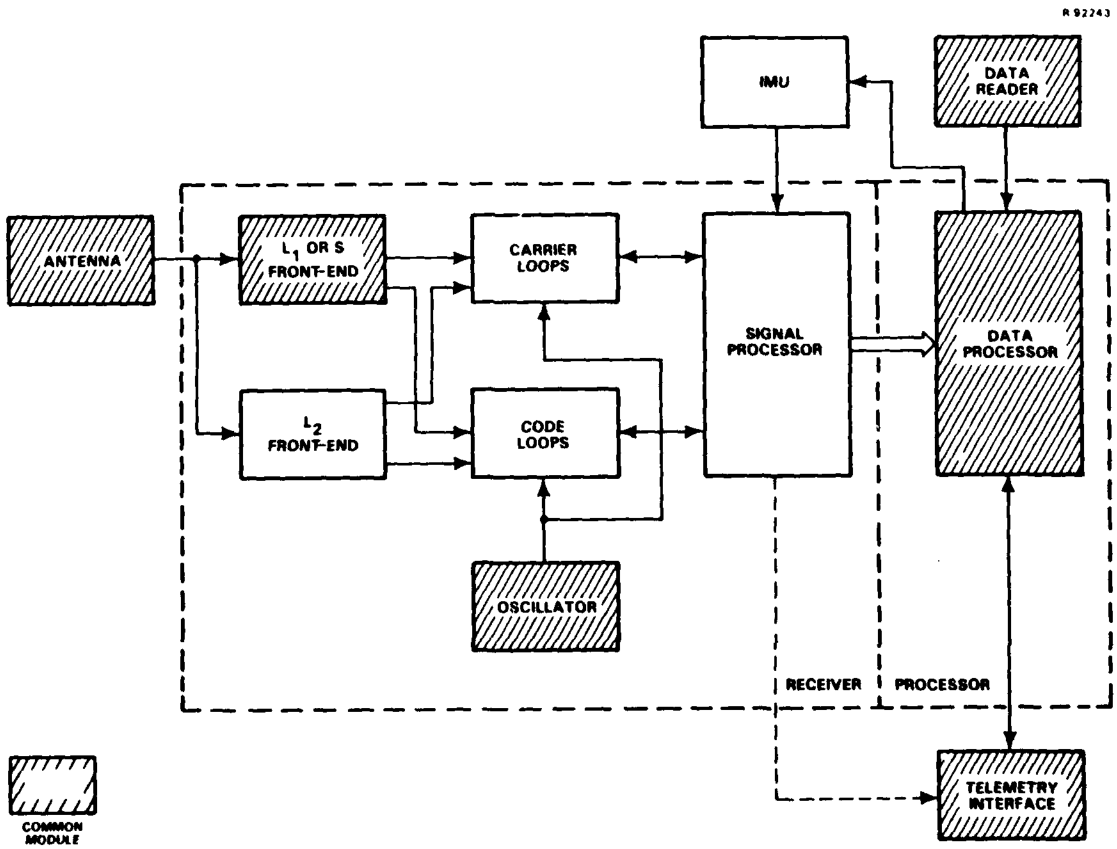

Figure 13.1-1 GPS Receiver Modules for Full and Basic Capability Receivers

13.1.2 Translator Characteristics

Both Low and High Power Translators should be developed to receive C/A-code signals broadcast on L_1 frequency. Each should be capable of accepting an external power source and outputing the local oscillator frequency (pilot tone) along with the translated GPS signals. Other features should include selectable output frequencies and power levels.

To support these translators, a family of L-band and S-band antennas must be developed which are suitable for large and small missiles, small drones, or pods. Also, a data interface which can accept both translator outputs and IMU aiding signals should be developed. In addition, optional modular add-ons such as an I and Q transdigitizer and an encoder or encryptor are candidates for common module development. Figure 13.1-2 (excerpted from Section 3.4) shows the optional translator configurations.

13.2 RANGE SUPPORT EQUIPMENT

The equipment needed to support Gr -specific range operations includes differential GPS stations, timing and survey receivers, translator signal receivers, and pseudolites. A standardized downlink and uplink system may also be desired to support GPS-based testing. Rawinsonde translators may be included in the list of support equipments although it appears that the payoff may be low. If the Low Power Translator satisfies the size, weight and power constraints associated with this application, it should be considered: otherwise, a special development effort does not appear to be warranted.

The differential GPS station should consist of a Basic Capability Receiver coupled with a modular GPS antenna and a

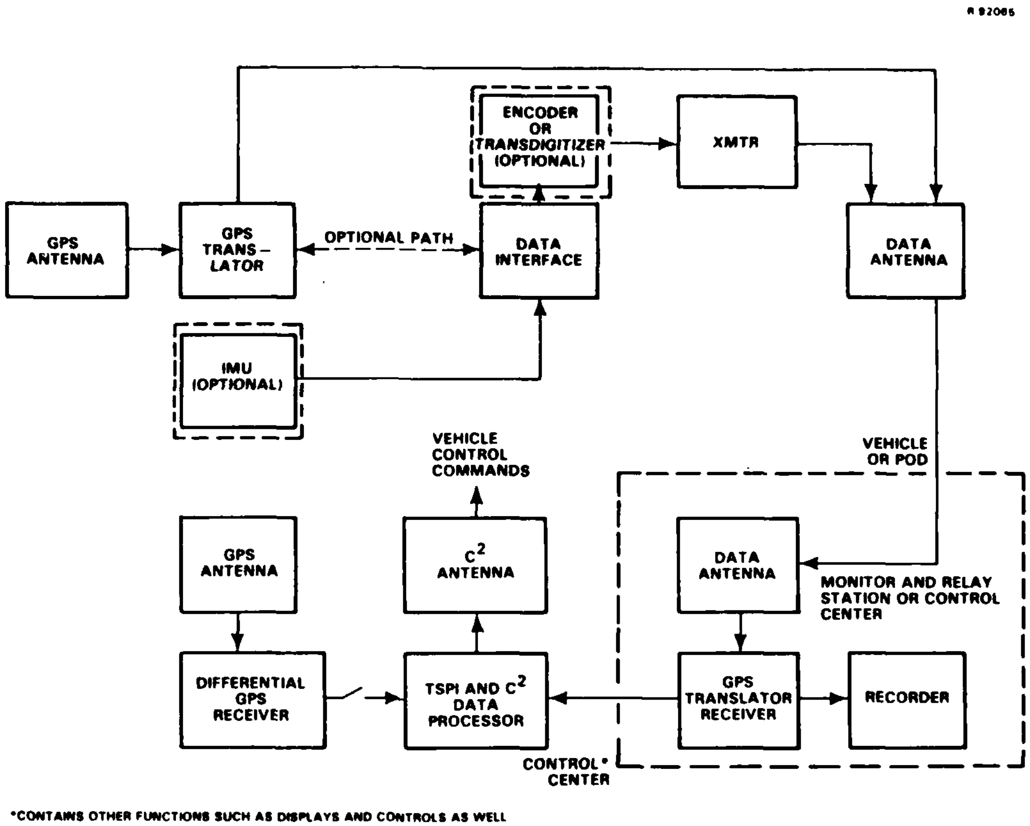

Figure 13.1-2 Onboard or Pod Translator Configuration

communications capability. The Basic Capability Receiver should suffice because the errors to be calibrated change very slowly with time. Communications are necessary for either broadcasting corrections to the test articles or to a control center.

The remaining support equipments should need little or no development. For example, timing and survey receivers should be available as commercial, off-the-shelf items within the next four years, while pseudolites have been built and are currently in operation at Yuma Proving Ground. The latter may require some development, however, to handle scenarios with large numbers of vehicles and a number of other pseudolite

arrays (See Section 3.3). The translator signal receiver, as has been previously discussed, will not require extensive development as it will consist of the Full Capability Receiver with an S-band front-end. A matrix of the potential applications for GPS user and range equipments is presented in Table 13.1-2.

TABLE 13.1-2

POTENTIAL APPLICATIONS FOR GPS RECEIVERS AND TRANSLATORS

APPLICATIONS	TEST ARTICLE RECEIVERS		TRANSLATORS		GEOCEIVER	TIMING RECEIVER
	FULL CAPABILITY	BASIC CAPABILITY	LOW POWER	HIGH POWER		
Test Articles						
• Aircraft	X*	X	X*			
• Drones	X*	X	X			
• Large Short Range Missiles	X*		X*			
• Small Short Range Missiles			X*			
• Land Vehicle		X				
• Ships		X				
• Strategic [illegible]sile				X		
• Anti-Ballistic Missile	X*++		X*++	X		
• Anti-Satellite Missile				X*		
• Cruise Missile	X		X*			
Baseline Range Equipment:						
• Differential GPS Reference		X				
• Translator Receiver	X†					
• Rawinsonde Tracker			X			
• Survey			X**		X	
• Time Reference						X

*IMU Aiding Desirable

†Translator Signal Receiver With S-Band Front-End Module

**SMILS Positioning

++High "g" Endo-Atmospheric Interceptor May be Poor GPS Application

13.3 IMPLEMENTATION ISSUES

Several issues relating to implementing a GPS-based TSPI capability deserve further investigation. Several of these have been discussed at length earlier: utilization of

operational receiver outputs (Section 3.2), multiple access interference on the inverted range (Section 3.1), multipath interference (Section 3.1), and antenna masking for pod-mounted receivers (multiple references). Other issues have either been mentioned only briefly, such as the need to validate the differential GPS concept over extended ranges, develop techniques for inverted range power management, and determine the viability of IMU/translator synchronization for ground-based inertial aiding. Additional issues deserving attention include pseudolite code allocation and the potential of alternate communication systems to serve as data and C^2 links. It is recommended that each of these issues be prioritized and resolved using a combination of analysis and field tests to ensure that GPS integration into the range environment is accomplished with minimal risk.

APPENDIX A
GPS SIGNAL ACQUISITION/REACQUISITION

A.1 INTRODUCTION

This appendix discusses the issues involved in acquiring/reacquiring a GPS signal as well as the time required to establish a navigation fix. The discussion focuses on P-code acquisition since C/A-code acquisition is a part of the P-code acquisition process. An explanation of the need for an indirect method of acquiring the P-code, as well as the functional dependence of time-to-acquire/reacquire on signal-to-noise density, C/N_o, and on residual line-of-sight dynamics is included. The nature and complexity of the GPS acquisition process results from the GPS signal structure. The relevant properties of the signal structure are discussed in the next section, followed by a discussion of the actual acquisition/reacquisition process including navigation fix times.

A.2 GPS SIGNAL STRUCTURE

The Global Positioning System (GPS) navigational signal is a composite waveform consisting of a Precise (P) Signal and a Coarse/Acquisition (C/A) Signal transmitted in phase quadrature. The C/A-signal is designed for commercial and other users not requiring the highest accuracy and desiring to use low cost equipment. <u>From a military standpoint, its primary function is in providing a method of acquiring the protected code.</u> The protected code is designed for both the highest navigation accuracy and for high anti-jam protection. The [illegible]

AD-A128 953 GPS (GLOBAL POSITIONING SYSTEM) RANGE APPLICATIONS STUDY(U) ANALYTIC SCIENCES CORP READING MA R G BALDWIN ET AL. 31 DEC 82 TASC-TR-4175-1

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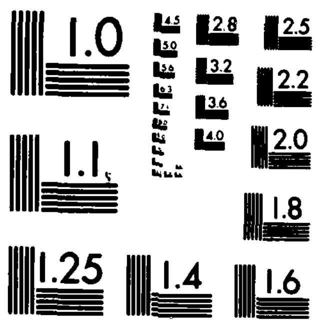

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

design, is easy to acquire but is highly susceptible to jamming. On the other hand, the P-signal, having been designed to resist jamming*, is nearly impossible to acquire directly without a priori range information; hence, the need for an indirect acquisition procedure.

Each signal transmitted by a given satellite (P and C/A) consists of a carrier wave modulated by both 50 Hz data and a bi-phase digital ranging code. The data consists of space vehicle ephemerides, system time-of-day, C/A to P handover information†, etc. The bi-phase digital codes are derived from a class of digital codes known as pseudo-random noise sequences (PRN sequences). The spread spectrum nature of the codes makes them ideal for highly accurate ranging while providing high anti-jam (A/J) protection.

The PRN sequence used for the C/A ranging code is composed of $\simeq$1000 nsec (300 m) chips with a code repetition period (i.e., code length) of 1023 chips (1 msec). Whereas, the PRN sequence for the P-code is composed of $\simeq$100 nsec (30 m) chips with a code repetition period of 6×10^{12} chips (7 days). The narrower chip width gives the P-code a factor of ten improvement in ranging accuracy over the C/A code. The longer code period gives the P-code added protection against jamming while denying its use to unauthorized users. The sequences are similar in that they have very sharp autocorrelation functions; i.e., if a PRN sequence is correlated with a replica of itself that differs by more than a chip, then the resulting signal has essentially zero power. Thus, for a GPS receiver

*The P-code has a seven day period which, while making direct acquisition quite difficult, is the very feature which gives the P-code its anti-jam resistance.

†The handover information enables acquisition of the P-signal with a minimum of search time.

to detect a GPS RF signal, it must correlate the incoming signal with a replica of the code delayed by less than a chip. Otherwise, the effective signal-to-noise ratio, SNR, is ~-30 dB for the P-code (-20 dB for the C/A-code). This compares with an SNR as great as 40 dB for perfect correlation. Therefore, a transmitted signal modulated by a PRN sequence is inherently nonobservable to a receiver that does not know the repetition time of the PRN sequence.

A.3 GPS SIGNAL ACQUISITION AND REACQUISITION

The term acquisition denotes the synchronization of carrier and code phases of the user GPS receiver with the satellite transmitted P- or C/A-code. The acquisition procedure is therefore the first step in establishing a navigation fix. The user must demodulate the GPS data after closed loop tracking is achieved. This demodulated data is then decoded and combined with pseudo-range and delta range measurements in an appropriate algorithm before computing a navigation fix. The time required to perform this entire operation is called the time-to-first-fix, TTFF, and is composed of the acquisition time, the data demodulation time, tracking time, and the navigation fix time.

The structure of the GPS signal is such that two distinct methods of acquiring the P-code are available to the user: direct and normal. For the direct method, á priori information is utilized to define a time-frequency uncertainty region for the P-signal. This region is then searched to determine the signal's code position and carrier frequency so that tracking may be initiated. Because the P-signal is designed to be secure, direct acquisition may require unsatisfactorily long acqusition times unless accurate á priori information is available to the user.

For the normal method, á priori information is employed to define a time-frequency uncertainty region for the C/A-signal. This region is then searched to determine the code position and carrier frequency so that tracking can begin. The tracking operation (for the C/A-signal) and associated data demodulation continues until the handover word (which is present in the data signal) is recovered -- handover words are present in the GPS data every six seconds. This word provides the information required to acquire the P-signal directly in a reasonable length of time. A brief, direct acquisition of the P-signal is the final step in the normal method. When the á priori information available to the user is not extremely accurate, the normal method will provide substantially better acquisition times than the direct method.

There are several factors which affect the acquisition time of a receiver. An obvious factor is the quality of the á priori information about range delay and doppler shift of the GPS signal. This factor is determined by uncertainties in the position and velocity of the user relative to the satellite, and by uncertainties in the time and frequency of the user's clock. Other factors influencing acquisition time include the received SNR, the desired probability of a correct acquisition, the search pattern used to check each cell in the time-frequency uncertainty region, and the structure of the acqusition receiver.

The á priori range-velocity uncertainty defines a code position-frequency uncertainty region which must be searched by the receiver*. The acquisition procedure is initiated by testing a code position and doppler frequency. This test is

*If previous receiver operation has not provided GPS system time, then an additional range uncertainty equal to the time error must be included. This is typically small compared with the range uncertainty.

accomplished by replicating the received signal as it would exist under the assumption that the test parameters are correct. In the simplest case, this signal is then correlated with the actual received signal, bandpass filtered, and then signal power detected. If the assumed doppler frequency is incorrect, the mixed signal will not pass the bandpass filter. Similarly, if the assumed code position is incorrect by more than a chip, the SNR will be -20 dB for the C/A-code (-30 dB for the P-code). If the test parameters are close to the correct values, the SNR will be as great as 40 dB. If the cross-correlation of the received signal and the locally-generated signal estimate (with the assumed code position and doppler frequency) do not pass a predetermined energy threshold, those signal parameters are rejected, and the local signal estimate is sequentially stepped through the uncertainty region until the energy exceeds the threshold. When the threshold is exceeded, operation is switched to the tracking mode.

Assuming a low cost GPS set in which all tests must be performed serially*, Fig. A.3-1 depicts the time to acquire a C/A-signal for a 300 meter range uncertainty as a function of doppler uncertainty and C/N_o, i.e., GPS signal strength at the receiver input. The results assume probability of detection, $P_D=0.9$, and probability of false alarm, $P_F=10^{-4}$. Each curve within the family of 5 curves is composed of three regions designated by a solid curve, a dashed curve, and a dotted curve. The dashed and dotted curves employ slight variations of the acquisition procedure defined above in order to

*This assumes there are not multiple channels available which could be employed to perform testing in parallel.

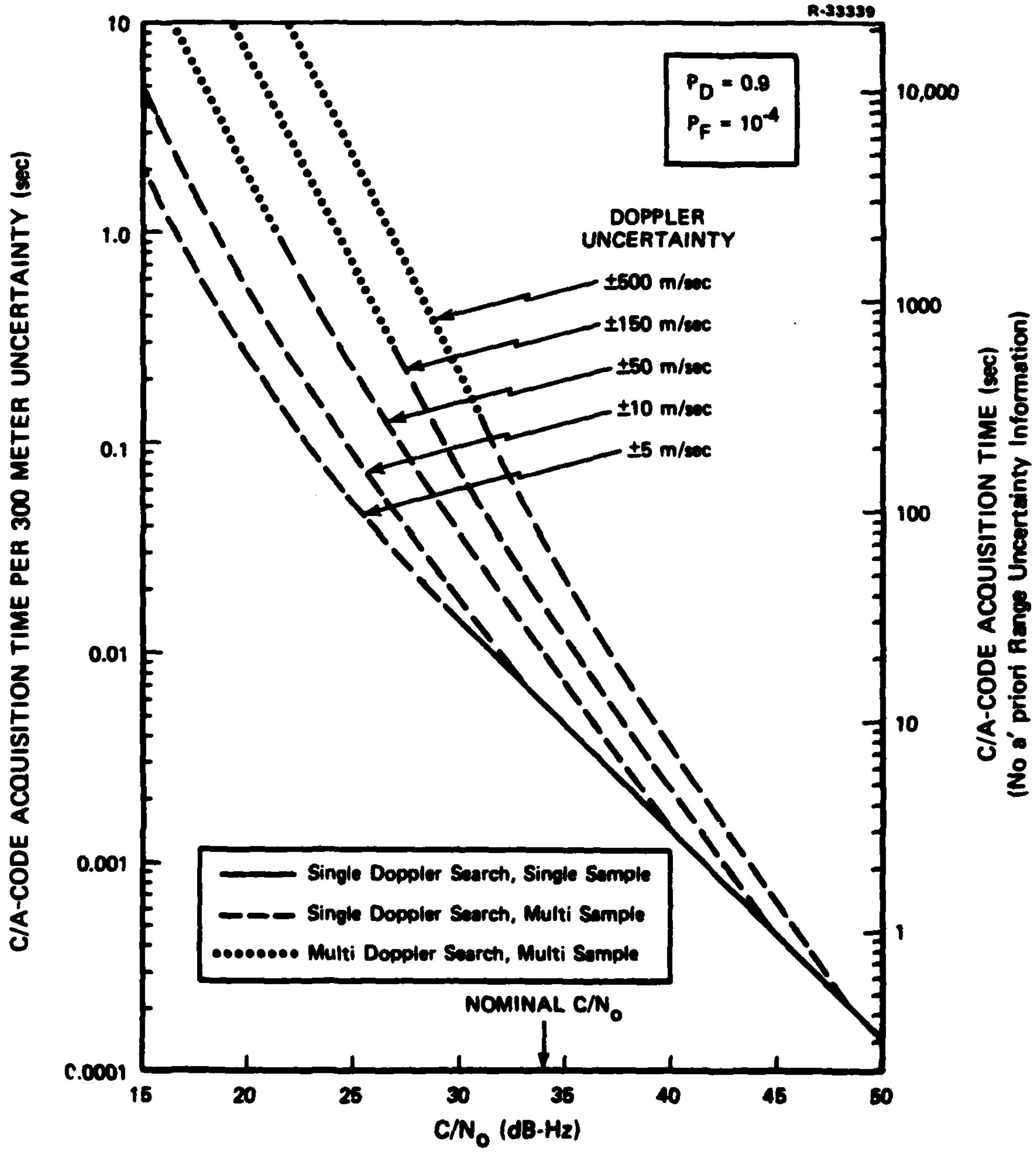

Figure A.3-1 Time to Acquire/Reacquire the C/A-Code as a Function of C/N_o, and Position and Velocity Uncertainties

optimize acquisition performance under weak signal conditions*. For a 600 meter uncertainty, the times indicated in the table double, etc. It should be noted that, in the worst case, no á priori range information is required for C/A acquisition; i.e., since the signal is periodic, the time uncertainty is limited to the code period, 1023 msec. Thus, with no á priori range information, a maximum 1023 chips must be tested (and typically codes are tested every 1/2 chip) for a total number of 2046 tests. In Fig. A.3-1 a scale has been added for the total acqusition time (right hand side) for one C/A channel as a function of C/N_o assuming no á priori range information.

Figure A.3-2 is analogous to Fig. A.3-1; it depicts the time to acquire a P-signal for a 300 meter range uncertainty as a function of doppler uncertainty and C/N_o. Again, the times double for a 600 meter uncertainty. Since the P-code has a 7-day period, there is no corresponding right hand scale depicting acquisition time if no á priori range information is known; i.e., the time would be prohibitive.

These acquisition times can be combined with the data demodulation time, tracking time, and the navigation fix time to provide the time-to-first-fix (both normal and direct). The data demodulation time is the time required to demodulate the entire data block (1500 bits) in order to recover the necessary satellite data for utilization in the navigation algorithm. Since the data is transmitted at a 50 Hz rate, this operation

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*The solid curve assumes only a single doppler frequency is searched. As C/N_o decreases, a sequence of independent samples at the output of the detector are required as the basis for detection, (dashed curve). The number of samples available depends on how long the doppler accuracy will keep the test code within a half chip of the received code. A further decrease in C/N_o requires multiple doppler regions to be searched in addition to multiple code positions, (dotted curve).

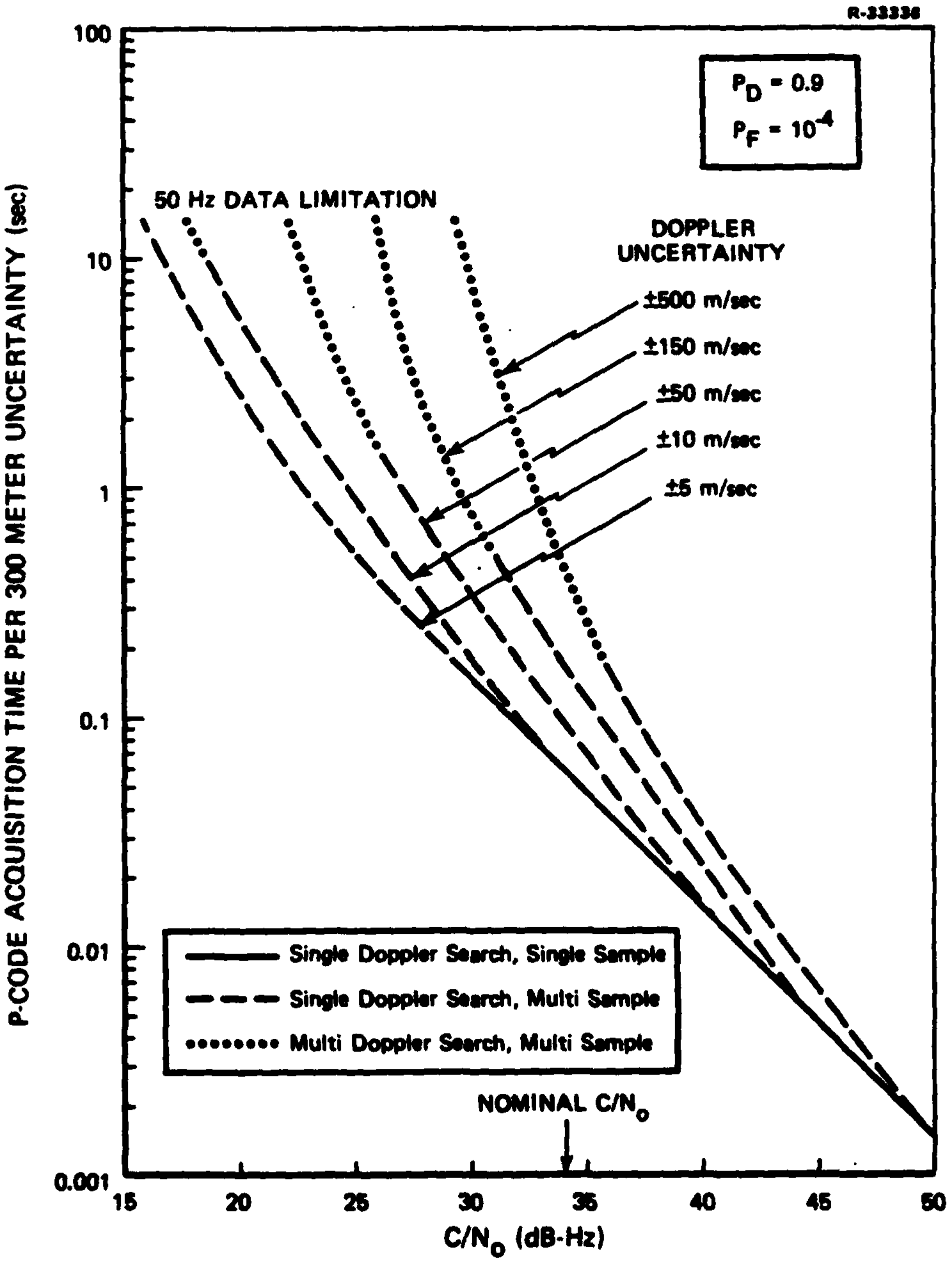

Figure A.3-2 Time to Acqure/Reacquire the P-Code as a a Function of C/N_o, and Position and Velocity Uncertainties

requires 30 seconds following bit synchronization (<1 sec). The tracking time governs the accuracy of pseudo range and delta range measurements. Its value depends on the receiver bandwidths; values of 2 to 6 seconds are reasonable. Finally, the navigation fix time, which depends upon the user's computation capabilities and the fix algorithm, will typically require approximately 1 second.

Table A.3-1 lists the times associated with the individual factors that make up the time-to-first-fix for the P-signal. Several points should be noted:

- If the range-doppler uncertainty is small enough to allow P-code acquisition in less than ≃8 seconds (see Fig. A.3-2), then direct acquisition is faster than normal acquisition
- The time required to demodulate the data block (30 seconds) can make up the major portion of time-to-first-fix, TTFF
- A low cost sequential set (1 channel set) affects TTFF by introducing a factor of four increase in TTFF* relative to a four channel set.

An example may help to clarify the discussion. Assume the signal-to-noise density (C/N_o) is 30 dB-Hz, the total velocity uncertainty is ± 150 m/sec, the total range uncertainty is 3000 meters (≃ 2 miles), and the user has a single channel receiver. Then, assuming also 4 seconds to derive pseudo-range and delta range, both normal and direct acquisition would take ≃ 169 seconds; 120 seconds of wich are required to demodulate the data block. The direct approach would be faster if C/N_o increased or if doppler uncertainty and/or range uncertainty decreased.

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*Less the time required to perform the navigation fix.

TABLE A.3-1

TIME-TO-FIRST-FIX FOR THE P-SIGNAL

ACQUISITION PHASE	NORMAL ACQUISITION	DIRECT ACQUISITION
Acquire Carrier and C/A-Code Phase (Depends on Position and Velocity Uncertainties)	$T_{C/A,\ ACQ}$ (Fig. A.3-1)	---
Obtain Bit Synch and Frame Synch	<1.0 sec	---
Demodulate and Decode Handover Word	6.0 sec	---
Acquiare P-Code	<1.0 sec	$T_{p,\ ACQ}$ (Fig. A.3-2)
Demodulate Data Block (1500 Bits @ 50 Hz)	30 sec	30 sec
Derive Pseudo-Range and Delta Range Measurements (Depends on Receiver Bandwidths)	$T_{Tracking}$†	$T_{Tracking}$†
Sum of Previous Times	T_{SUB}	T_{SUB}
N = 4 in Low Cost Sequential Set (N = 1 in 4 Channel Set)	$T_{SUB} \times N$	$T_{SUB} \times N$
Perform Navigation Fix (Depends on User Computer and Fix Algorithm)	~1 sec	~1 sec

†$T_{Tracking}$ governs the accuracy of the correlation process and therefore the measurement accuracy (values of 2 sec to 6 sec are reasonable)

The term reacquisition denotes the resynchronization of carrier and code phases of the user GPS receiver with the satellite transmitted P-code that must be accomplished whenever the tracking loops lose lock. Because closed loop tracking has already been achieved, demodulated GPS data is available to a user attempting reacquisition. Since GPS data changes slowly, this available data may be employed in the navigation algorithm once closed loop tracking has been re-established. Consequently, when the outage is brief, the normal reacquisition-fix-time

would be the acquisition time of the P-signal (Fig. A.3-2) plus ≃4 sec to derive pseudo range and delta range measurements, plus the navigation fix time. (This value is multiplied by four if a sequential single channel set is used.) Reacquisition-fix-time is naturally shorter than the time-to-first-fix since the necessity of data demodulation has been eliminated and since the position and velocity uncertainties are small. When the outage is sufficiently long, faster reacquisition can be accomplished by first locking-up the C/A-signal and then reacquiring the P-code by the handover word; this is referred to as the indirect reacquisition method. Table A.3-2 lists the times associated with the factors that make up the reacquisition-fix-time for the P-signal for both the normal and indirect reacquisition methods. This table differs from Table A.3-1 primarily in there being no time required to demodulate the data block.

A.3 SUMMARY

This appendix has discussed the issues involved in acquiring/reacquiring a GPS signal and the time required to establish a navigation fix. The complexity of the acquisition/reacquisition process resulted from the structure of the GPS signal; namely, unless both the pseudo-random code modulating the GPS signal as well as the time when the code repeats are known to a receiver, the GPS signal is inherently non-observable; i.e., buried in the noise. To account for the GPS signal structure, there are two methods available for performing both acquisition and reacquisition: the normal and direct method for acquisition, and the normal and indirect method for reacquisition.

The time required to first establish a navigation fix is referred to as time-to-first-fix, TTFF. TTFF for the P-

TABLE A.3-2

REACQUISITION-FIX-TIME FOR THE P-SIGNAL

ACQUISITION PHASE	NORMAL REACQUISITION	DIRECT REACQUISITION
Acquire Carrier and C/A-Code Phase (Depends on Position and Velocity Uncertainties)	---	$T_{C/A,\ ACQ}$ (Fig. A.3-1)
Obtain Bit Synch and Frame Synch	---	<1.0 sec
Demodulate and Decode Handover Word	---	6.0 sec
Acquire P-Code	$T_{p,\ ACQ}$ (Fig. A.3-2)	<1.0 sec
Derive Pseudo-Range and Delta Range Measurements (Depends on Receiver Bandwidths)	$T_{Tracking}$†	$T_{Tracking}$†
Sum of Previous Times	T_{SUB}	T_{SUB}
N = 4 in Low Cost Sequential Set (N = 1 in 4 Channel Set)	$T_{SUB} \times N$	$T_{SUB} \times N$
Perform Navigation Fix (Depends on User Computer and Fix Algorithm)	~1 sec	~1 sec

†$T_{Tracking}$ governs the accuracy of the correlation process and therefore the measurement accuracy (values of 2 sec to 6 sec are reasonable)

signal is tabulated in Table A.3-1 for both the normal and direct methods of acquisition. The normal method requires acquisition of the C/A signal; the acquisition time is shown in Fig. A.3-1 in terms of C/N_o, and position and velocity uncertainties. The direct method of acquisition requires acquisition of the P-signal; this acquisition time is shown in Fig. A.3-2.

When the GPS receiver loses lock, resynchronization of the carrier and code phases with the transmitted P-signal must be accomplished before the next navigation fix can be

obtained. The time required to obtain the navigation fix is referred to as reacquisition-fix-time. Reacquisition-fix-time for the P-signal is tabulated in Table A.3-2 for both the normal and indirect methods of reacquisition. The normal method requires reacquisition of the P-signal; this time is given in Fig. A.3-2 as a function of C/N_o, and position and velocity uncertainties. The indirect method of reacquisition requires reacquisition of the C/A-signal; this time is given in Fig. A.3-1.

The method used to acquire/reacquire a GPS signal will depend on the range and velocity uncertainties as well as on the signal-to-noise density, C/N_o. In particular, if uncertainties and C/N_o are such that the P-code can be acquired within 6-8 seconds, then direct acquisition process will be faster than the normal method. Similarly, if the P-code can be reacquired within 6-8 seconds, then the normal reacquisition process will be faster than the indirect method.

GLOSSARY

A-A	Air-to-Air
ABM	Anti-Ballistic Missile
ACM	Air Combat Maneuvering
ACMI	Air Combat Maneuvering Instrumentation
AD	Armament Division
AFFTC	Air Force Flight Test Center
AFTFWC	Air Force Tactical Fighter Weapons Center
AFWTF	Atlantic Fleet Weapons Training Facility
AMRAAM	Advanced Medium Range Air-to-Air Missile
APC	Armored Personnel Carrier
ARIA	Advanced Range Instrumentation Aircraft
A-S	Air-to-Surface
ASAT	Anti-Satellite Missiles
A/J	Anti-Jam
BW	Bandwidth
C/A	Coarse/Acquisition
CAP	Combat Air Patrol
C^2	Command and Control
CDEC	Combat Developments Experimentation Command
CDU	Computer Display Unit
C/N_o	Carrier-to-Noise Density Ratio (dB-Hz)
CTS	Cooperative Tracking System
DOD	Department of Defense
DOP	Dilution-of-Precision
DT&E	Development Test and Equipment
ECM	Electronic Countermeasure
EM	Electro-Magnetic
ESMC	Eastern Space and Missile Center
EW	Electronic Warfare
FALLON	Fallon
FSED	Full-Scale Engineering Development
GPS	Global Positioning System
GDOP	Geometric Dilution-of-Precision
GT	Ground Transmitter
HDOP	Horizontal Dilution-of-Precision
HOW	Handover Word

GLOSSARY (Continued)

IE	Instrument Equipment
IFF	Identification Friend or Foe
IIP	Instantaneous Impact Prediction
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
I/O	Input/Output
IRCC	Inverted Range Control Center
JPO	Joint Program Office
JT&E	Joint Test and Evaluation
JTIDS	Joint Tactical Information Distribution System
KMR	Kwajelein Missile Range
LCC	Life Cycle Cost
LCIGS	Low Cost Inertial Guidance System
LOS	Line-of-Sight
MARVs	Maneuvering Reentry Vehicles
MLRS	Multiple Launcher Rocket System
MOM	Measures-of-Merit
MROC	Mobile Range Operations Center
MSL	Mean Sea Level
MTBF	Mean Time Between Failures
NASA	National Aeronautic and Space Administration
NATC	Naval Air Test Center
NTC	National Test Center
NWC	Naval Weapons Center
O&M	Operations & Maintenance
OT&E	Operational Test and Evaluation
OTH	Over The Horizon
P_D	Probability of Detection
PDOP	Position Dilution-of-Precision
P_F	Probability of False Alarm
PIP	Participant Instrumentation Package
PMRF	Pacific Missile Range Facility
PMTC	Pacific Missile Test Center
PN	Pseudo Noise
PRN	Pseudo Random Noise

GLOSSARY (Continued)

R^3	Relay, Report, Respond
RB	Reentry Body
RF	Radio Frequency
RMS	Range Measurement System
ROM	Rough Order of Magnitude
RSS	Root Summed Squared
S-A	Surface-to-Air
SAM	Surface-to-Air Missile
SATRACK	Satellite Tracking System
SLBM	Submarine Launched Ballistic Missile
SMILS	Sonobuoy Missile Impact Locating System
SNR	Signal-to-Noise Ratio
S-S	Surface-to-Surface
SV	Satellite
SVT	State Vector Tracking
TACTS	Tactical Air Combat Training System
TCATA	TRADOC Combined Arms Test Activity
TLM	Telemetry
TSPI	Time Space Position Information
TTFF	Time-to-First-Fix
TWS	Tactical Weapon Antenna
UE	User Equipment
UTC	Universal Time Coordinates
UTTR	Utah Test and Training Range
VACAPES	Virginia Capes
VDOP	Vertical Dilution-of-Precision
WSMC	White Sands Missile Range
WSMR	Western Space and Missile Range
XMTR	Transmitter
YPG	Yuma Proving Grounds

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